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PAPERS FROM THE DEPARTMENT

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GEOLOGY.

No. 14.—THE MONTEREGIAN HILLS—A CANADIAN PETROGRAPHICAL PROVINCE.

BY

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THE MONTEREGIAN HILLS—A CANADIAN PETROGRAPHICAL PROVINCE.

GENERAL STATEMENT.

IN the province of Quebec between the enormous expanse of the Laurentian highlands to the northwest, constituting the "Canadian Shield," and the disturbed and folded tract of country to the southeast which marks the Appalachian uplift, there is a great plain underlain by nearly horizontal rocks of Lower Paleozoic age. This plain, while really showing slight differences of level from place to place, seems to the casual observer perfectly flat. Its surface is mantled with a fertile soil consisting of drift redistributed upon its surface by the sea which at the close of glacial times covered it. The uniform expanse of this plain, however, is broken by several isolated hills composed of igneous rocks, which rise abruptly from it and which constitute very striking features of the landscape. It was at the foot of one of these hills rising by the side of the river St. Lawrence, and which he named Mount Royal, that Jacques Cartier on his first visit found the Indian encampment of Hochelaga, whose site is now overspread by the city of Montreal, which has not only grown around the foot of the hill, but has extended up its sides and has reserved its summit as a park.

From the top of Mount Royal the other hills referred to can all be seen rising from the plain to the east, while to the north the plain stretches away unbroken to the foot of the Laurentian country.

As has been remarked by Sir Archibald Geikie:[1]

> The word "mountain" is properly speaking not a scientific term. It includes many forms of ground utterly different from each other in size, shape, structure, and origin. In a really mountainous country the word would be restricted to the loftier masses of ground, while such a word as "hill" would be given to the lesser heights. But in a region of low or gently undulating land, where any conspicuous eminence becomes important, the term "mountain" is lavishly used. In eastern America this habit has been indulged in to such an extent that what are, so to speak, mere hummocks in the general landscape are dignified by the name of mountain.

The hills under consideration, while by no means "mere hummocks," being situated in such a country of low relief, seem to be higher than they really are and are always referred to locally as "mountains."

These mountains, whose positions are shown on the accompanying map (Fig. 1), are eight in number, their names and their height above sea level being as follows:

Mount Royal	769.6 feet
Montarville or Boucherville mountain	Not yet accurately determined
Beloeil	1,437 feet (Leroy)
Rougemont	Not yet accurately determined
Yamaska	
Shefford	1,600 feet (Dresser)
Brome	1,440 feet (Dresser)
Mount Johnson or Monnoir	875 feet

Brome mountain is by far the largest of the group, having an area of 30 square miles. Shefford comes next in size, having an area of rather less than nine square miles, while Mount Johnson, which is very much smaller than any of the others, has an area of only .422 of one square mile.

Of these eight, the first six, as Logan[2] notes, "stand pretty nearly in a straight line," running approximately east and west, Mount Royal being the most westerly, and the others following in the order in which they are enumerated above, until Shefford mountain is reached, which is the most easterly member of the series. The distance from Mount Royal to Shefford is fifty

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[1] *Text-Book of Geology.*

[2] *Geology of Canada*, p. 9.

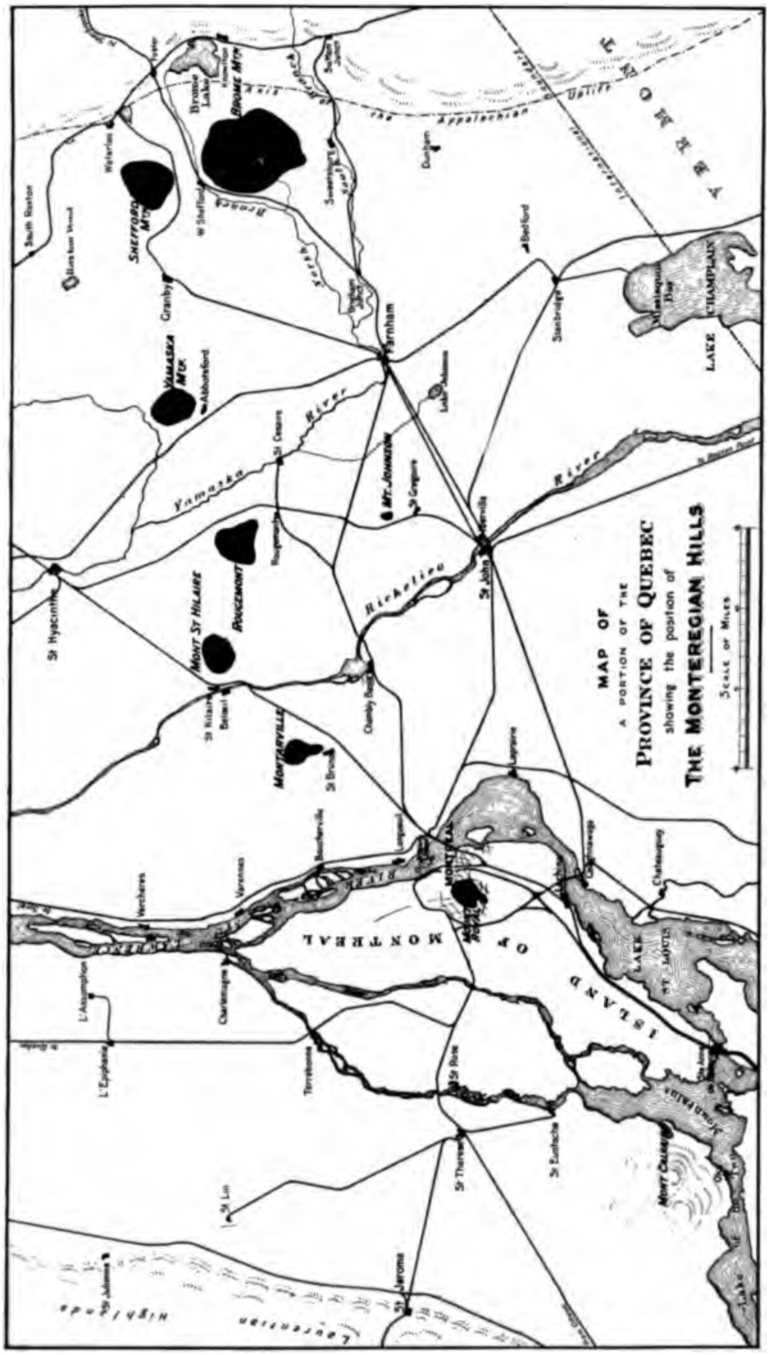
MAP OF
A PORTION OF THE
PROVINCE OF QUEBEC
showing the position of
THE MONTEREGIAN HILLS
SCALE OF MILES
SHEFFORD MTN
BROME MTN
Brome Lake
YAMASKA MTN
MT. JOHNSON
ROUGEMONT
MONT ST HILAIRE
MONTARVILLE
MOUNT ROYAL
MONT CALVAIRE
Yamaska River
Richelieu River
LAKE CHAMPLAIN
Missisquoi Bay
LAKE ST. LOUIS
Lake of Two Mountains
ISLAND OF MONTREAL
MONTREAL
Laurentian Highlands
Axis of the Appalachian Uplift
Waterloo
Granby
South Roxton
Abbotsford
St Hyacinthe
St Cesaire
Farnham
Bedford
Stanbridge
St John
St Gregoire
Rougemont
St Hilaire
Beloeil
Chambly
St Bruno
Boucherville
Longueuil
Laprairie
Varennes
Verchères
Lachine
Caughnawaga
Chateauguay
L'Assomption
L'Epiphanie
Charlemagne
Terrebonne
St Rose
St Therese
St Eustache
St Lin
St Jerome
Dunham
Sutton

FIG. I.

miles. Mount Johnson and Brome mountain lie on a line parallel to them, but a short distance to the south, Rougemont being the nearest neighbor to Mount Johnson and Brome mountain being immediately south of Shefford. It is highly probable, in view of this distribution, that these ancient volcanic mountains are, as is usual in such occurrences, arranged along some line or lines of weakness or deep-seated fracture. The "pretty nearly straight line" referred to by Logan on which the first six mountains of the group are situated must be considered either as a single line with a rather sharp curve in the middle, or as made up of two shorter straight lines, each with three mountains, which diverge from one another at an angle of about 30°, Montarville being located at the point of intersection. Mount Johnson and Brome mountain might then be considered as situated on short subsidiary fractures.

Brome and Shefford, however, which are the two largest mountains of the series and which are only separated by a distance of a little over two miles, are probably connected at no great depth below the surface, forming in reality one large mass, while Mount Johnson, like the similar volcanic necks of Fife and Würtemberg, may have no direct connection with any line of fracture. It must be noted, as mentioned by Dresser,[1] that while six of these mountains rise from the horizontal strata of the plain, the two most easterly members of the group, named Shefford and Brome, while still to the west of the axis of the range, lie well within the folded belt of the Appalachians, though, owing to the extensive denudation from which the region has suffered, this folding has had but little influence on the local topography.

No collective name has hitherto been proposed for this remarkable group of hills.[2] From their intimate geological

[1] "On the Petrography of Shefford Mountain," *Amer. Geol.*, October, 1901.

[2] The only instances in which these hills have been referred to as a geographical unit are, so far as can be ascertained, in a paper by STERRY HUNT entitled "On Some Igneous Rocks of Canada," *Am. Jour. Science*, March, 1860, where they are called the Montreal group; and by ELIE DE BEAUMONT, who in a late edition of his *Systèmes des Montagnes* included these hills as one of his systems, under the name of the "Système de Montréal." See PRESTWICH, *Geology, Chemical, Physical and Stratigraphical*, Vol. I, p. 294.

relationship, however, constituting as they do a distinct and remarkable petrographical province, such a name is required. I propose to call them the *Monteregian Hills*, deriving their name from Mount Royal ("Mons Regius"), which may be taken as their type, being as it is the best-known member of the group.

There are certain other hills which have been considered by former workers in the geology of this district to belong to this group. Thus Logan thought that Rigaud Mountain, situated near the margin of the plain, by the river Ottawa, about forty miles west of Mount Royal, was "probably connected with" the series.[1] Ells[2] also included Mont Calvaire, a large, low mass which rises from the plain immediately to the north of the Lake of Two Mountains, near the junction of the Ottawa and the St. Lawrence.

Ells also refers to "the hills on the west side of Memphremagog lake and to the northeast toward the Chaudière river and beyond" as bearing a marked resemblance to the rocks of Mount Royal, Yamaska, etc., and as probably being of the same age.[3]

In a careful study of Rigaud mountain, recently completed by Mr. Leroy,[4] of this university, it is shown that the rocks constituting this mountain are different in character from those of the Monteregian hills, being composed of a reddish hornblende syenite and a quartz-bearing porphyry. These rocks, however, were found to be identical in character and composition with a great area of syenite, cut by porphyry, mentioned by Logan as occupying some forty square miles in the townships of Chatham and Grenville on the margin of the Laurentian plateau, a few miles to the north of Rigaud mountain. Owing to the drift which mantles this district, the actual contact of the igneous rock of Rigaud mountain and the Paleozoic strata of the plain is nowhere visible, so that it is impossible to determine whether the mass of Rigaud mountain cuts through the strata in question, as in the case of the Monteregian hills, or whether it is pre-Paleozoic in age. The same is true of the mass in Chatham and Grenville, the actual contact here also being found by Mr. Leroy to be banked up with drift. The narrow margin of gneiss shown on Logan's map[1] between the Chatham syenite and the Paleozoic is also conjectural, the area being likewise drift-covered. Rigaud mountain is furthermore of a different shape from the mountains east of Montreal, being six miles in length and only two and one-half miles wide; at the eastern end of it, moreover, there is found an occurrence of ordinary Laurentian gneiss. The abrupt and straight southern boundary of the Laurentian plateau along this part of its course probably marks a fault. Ells has noted the existence of other faults in this district, one of which he believes to follow the north side of Rigaud mountain. It is thus highly probable that the ridge known as Rigaud mountain does not belong to the Monteregian hills, but that it is a portion of the Laurentian plateau separated from the main area by faulting and stripped of its original covers of Paleozoic strata by denudation. It is probable that Mont Calvaire, as regarded by Logan, is also an outlying portion of the Laurentian plateau.

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[1] *Geology of Canada*, 1863, p. 9.

[2] "Report on a Portion of the Province of Quebec," *Ann. Rept. Geol. Surv. of Canada*, Vol. VII, Part J, 1896.

[3] Eastern Townships Map (Montreal Sheet), *Ann. Rept. Geol. Surv. of Canada*, Vol. VII, Part J.

[4] *Bull. of the American Geological Society*, Vol. XII, 1901.

The hills on the west side of Lake Memphremagog and to the northeast toward the Chaudière river, referred to by Dr. Ells, so far as is known, are quite different in petrographical character from Mount Royal and the other members of its group. They constitute a chain of hills occupying a tract of country some four miles wide and thirty-five miles in length, in the heart of the Appalachian uplift and following the strike of the Appalachian folding. Many of them, as Owl's Head and Orford mountain, rise to a very considerable height, these peaks having a height of about 2,400 and 2,800 feet respectively; forming, in fact, the highest elevations in this part of Canada. So far as has been ascertained, these mountains are in all cases composed of highly altered rocks. Many of them are altered diabases.[1] In other cases the alteration is so far advanced that it is impossible to determine the character of the original rock. Many of them have been completely altered to masses of serpentine. Nepheline-syenites, essexites, and similar rocks have not as yet been found anywhere in this chain of hills. A series of dyke rocks from Lake Memphremagog, examined by Marsters,[2] were found to be chiefly granites and lamprophyres, with one typical camptonite. It would seem therefore, that while our knowledge of these hills is as yet very imperfect, the evidence at our command, so far as it goes, points to them as belonging to a group quite distinct from Mount Royal and its associates. The petrographical province of the Monteregian hills may therefore, in the present state of our knowledge, be said to comprise only the eight mountains enumerated on p. 240, together with the consanguineous dykes which at many points are found cutting the rocks of the surrounding plains.

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[1] Atlas to accompany the *Geology of Canada*, 1863, Map No. 2.

The first description of these hills was that given by Logan and Hunt in the early years of the Canadian Survey. To Hunt especially we owe a somewhat extended description of the petrography of the group and a number of chemical analyses, more especially of the constituent minerals of certain of the rocks. These descriptions are, however, very general and often very imperfect, as must necessarily have been the case before the introduction of modern petrographical methods. Nor were certain important petrographical relationships observed which have in later times come to be recognized. This early work, however, is of great interest, and in case of three of the mountains, almost all the information which we have even at the present time, is derived from those early studies. The results of this work were brought together in the *Geology of Canada*, published by the Geological Survey of Canada in 1863, and are to be found on pp. 655–70. During the thirty years following the appearance of this volume, only three papers containing additional information concerning these rocks appeared. These were by

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[1] F. D. ADAMS, *Ann. Rept. Geol. Surv. of Canada*, 1880–81–82, pp. 12–13 A.

[2] *American Geologist*, July, 1895.

Harrington,[1] Lacroix,[2] and the present writer,[3] respectively, all dealing with Mount Royal. In 1896 the "Montreal Sheet" of the *Eastern Townships Map*, prepared by Ells, and embracing the district of the Monteregian hills, was published by the Geological Survey of Canada and accompanied by a geological report on this portion of the province of Quebec. Four years later Principal Dresser of St. Francis College, Richmond, aided by a small grant from the Geological Survey of Canada, made a careful study of Shefford mountain, and a preliminary paper embodying the chief results of his investigations appeared in 1901.[4] Mr. Dresser last summer extended his work to Brome mountain, and has since published a brief description of this occurrence.[5] Mr. O. E. Leroy, of McGill University, is now engaged in a study of Beloeil, and I am indebted to him for the facts concerning the geology of this mountain which are here presented. Montarville, Rougemont, and Yamaska mountains still await detailed study, but it is expected that they also will before long be put in commission.

In the present paper it is proposed first to gather together the more important facts concerning the geology of the Monteregian hills which are scattered throughout these various publications, revising some of the earlier work and embodying the results of later personal studies, and then to describe in some detail one of these hills—Mount Johnson—of which hitherto but little has been known.

PETROGRAPHY OF THE MONTEREGIAN HILLS.

Hunt distinguished four types of igneous rocks as constituents of the Monteregian hills. These he classed as trachyte, phonolite, diorite, and dolerite, respectively. In this classification no distinction was made between rocks occurring as dykes and the great igneous intrusions which form the body of the hills; differences in structure resulting from mode of occurrence were not considered, the classification being based upon mineralogical composition alone.

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[1] "On Some of the Diorites of Montreal," *Ann. Rept. of the Geol. Surv. of Canada*, 1877–78, 42 G.

[2] "Description des syénites néphélinitiques de Pousac et de Montréal (Canada) et de leurs phénomènes de contact," *Bull. Soc. Géol. de France*, 3e série, tome XVIII, 1890.

[3] "On a Melilite-Bearing Rock (Alnöite) from St. Anne de Bellevue near Montreal, Canada," *Amer. Jour. of Science*, April, 1892.

[4] "On the Petrography of Shefford Mountain," *Amer. Geol.*, October, 1901.

[5] *Summary Report of the Geological Survey Department for 1901*, p. 183.

Recent investigations have shown that Hunt's names do not convey an accurate idea of the petrography of these hills, nor do they set forth the interesting relationships of the various rocks composing them. It is necessary for this purpose to adopt a more modern nomenclature, for all the mountains of the group are composed of a family of consanguineous rocks, and taken together they present one of the finest examples of a petrographical province hitherto discovered. They consist, furthermore, of a rather rare class of rocks characterized by a high content of alumina and alkalies, especially soda.

The rocks forming the great intrusions which make up the mass of these mountains belong to two well-characterized types —one light in color, poor in iron-magnesia constituents, and comparatively high in silica; the other dark in color, rich in iron-magnesia constituents, and with a lower content of silica. They may be classed as follows, if Rosenbusch's nomenclature be followed:

1. Alkali-syenite, nepheline-syenite, or sodalite-syenite.
2. Essexite.

The first is an alkali-syenite, always containing a little nepheline, but this mineral in some cases becoming so abundant that the rock passes into a true nepheline-syenite, or, by the replacement of the nepheline by sodalite, into a sodalite-syenite. This in the case of Mount Johnson and Shefford mountain is represented by the variety known as pulaskite; in Brome mountain it is stated by Dresser to resemble Brögger's laurvikite,[1] while in Mount Royal and Beloeil it is a nepheline-syenite. At the latter mountain a sodalite-syenite also occurs in association with the nepheline-syenite. Nepheline-syenite is also known to form part of Yamaska mountain. In addition to the syenite of the pulaskite variety, Dresser found in Shefford mountain a large development of a distinctly more acid type of the syenite magma, the rock showing occasionally a few grains of quartz. This rock he has classed as nordmarkite. These light-colored syenites, together with certain dykes of bostonite having a general similarity in composition, were the rocks classed by Dr. Hunt as trachytes.

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[1] *Summary Report of the Geological Survey of Canada*, 1901, p. 187.

To the essexites belong the dolerites and diorites of Hunt, when he applied these terms to the great igneous intrusions of the mountains and not to mere dykes. They usually contain both hornblende and pyroxene, but the relative proportion of these two minerals varies considerably in the different occurrences. Olivine is sometimes present. Hunt did not recognize the presence of nepheline in these rocks, nor the highly alkaline character of the magma which they represent, and classified them as dolerite or diorite according to the preponderance of pyroxene or hornblende, noticing certain occurrences in which the former rock passed into a pyroxenite or peridotite.

The greater part of Mount Royal is composed of an essexite, usually very basic, the dark-colored constituents forming a very large proportion of the whole rock. This was classed by Hunt as a dolerite, but is almost identical with the essexite of Mount Johnson, which Hunt classes as a diorite. This same rock is stated by Hunt to make up the greater part of Montarville and Rougemont and to form a portion of Yamaska mountain. An examination of thin sections of specimens of the Rougemont rock in the petrographical collection at McGill University shows it to be an essexite, rich in olivine. Dresser has found it to constitute approximately one-half of Shefford mountain and also to form large areas in Brome mountain. It makes up the greater part of Mount Johnson and forms the mass of Beloeil.

It is thus seen that the essexite magma is represented in every one of the eight mountains, and that in six of them at least it is associated with the syenite magma. The remaining two, Montarville and Rougemont, which have not been thoroughly examined as yet, while certainly composed chiefly of essexite, will probably be found, on further study, to present a development of the syenite in some portions of their mass also.

In addition to these bodies of intrusive rock which form the mass of the mountains, great numbers of dykes occur cutting both the surrounding sedimentary strata and the intrusions. These are, of course, especially numerous in and around the mountains themselves, but are also occasionally found far removed from the centers of activity. The relative abundance of these dykes in the vicinity of the several mountains varies greatly. They swarm through the Paleozoic strata about Mount Royal, cutting the limestones in all directions and also traversing, although less frequently, the igneous rock of the main intrusion as well. No less than twenty-nine dykes and flows, belonging to at least four and possibly five separate series, each cutting the preceding set, were mapped by Dr. Harrington some years ago in an excavation measuring 220 yards by 100 yards which was opened up in the Trenton limestone on the flank of Mount Royal during the construction of the Montreal Reservoir extension. Dykes, in fact, abound wherever in the vicinity of Mount Royal the bedrock is exposed by the removal of the mantle of drift, as for instance at the Mile End Quarries, St. Helen's Island, and in the bed of the St. Lawrence about Point St. Charles when it is exposed at low water. The whole district about the city would present a network of dykes, could the overlying drift be removed.

Dresser mentions dykes as occurring abundantly about Shefford mountain. In Mount Johnson, on the other hand, they are almost entirely absent. Only five dykes could be found after a careful exploration of the whole occurrence, and they were of insignificent dimensions. But very few dykes also occur at Beloeil mountain. A large number of the dyke rocks have been collected from the various occurrences and are now awaiting investigation in the geological department at McGill University. The work on the dykes of Mount Royal is now well advanced and, it is hoped, will be ready for publication shortly. They form a most remarkable series, comprising bostonites, tinguaites, sölvsbergites, camptonites, fourchites, monchiquites, and alnöites. Most, if not all, of the types of dyke rocks which have been described as occurring in association with the alkaline rich magmas of the theralite and nepheline-syenite groups in any part of the world are thus represented. To these dyke rocks belong Hunt's phonolite, which he considered to differ from the trachyte in that it contained a certain proportion of natrolite. The two occurrences which he describes[1] are both from points near Montreal. They are nepheline bearing dykes in an advanced stage of alteration.

As has been mentioned, dyke rocks which from their composition are clearly connected with the intrusions of the Monteregian hills have been found cutting the rocks of the plain at very considerable distances from any of the main centers of activity. Thus, in addition to occurrences at Laprairie, Lachine, Rivière des Prairies, Ste. Anne de Bellevue, St. Paul's Island in the vicinity of Montreal, several dykes and flows of "trachyte" (bostonite) are noted by Hunt and Logan as occurring about Chambly, which is six miles to the south of the line of the Monteregian hills,[2] while the occurrence of a "dolerite" dyke at St. Hyacinth, ten miles north of the line, is mentioned.[3]

A sheet of trap evidently connected with these intrusions also occurs at St. Lin,[4] twenty-four miles north of this line, where it alters the Chazy limestones through which it cuts into a pink marble. It is very much decomposed, but evidently belongs to some variety of the nepheline or melilite dyke rocks above mentioned.[5]

Whether the camptonite and in some cases bostonite dykes, described by several authors from various points in the states of Maine, New Hampshire, and Vermont, adjacent to the Canadian line, and the still more distant occurrences of similar dyke rocks in the state of New York, are connected with the Monteregian hills, is not yet known. There seem to be no intrusions of nepheline-syenite or essexite hitherto discovered with which these southern dykes can be connected in the districts in which they occur. The umptekite intrusion of Red Hill, Moltonboro, N. H., is, however, closely related to the Monteregian pulaskite in character and composition, and may prove to be such a center.

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[1] *Geology of Canada*, pp. 659–61.

[2] *Ibid.*, pp. 209 and 657.

[3] *Ibid.*, p. 210.

[4] *Ibid.*, p. 133.

[5] F. D. ADAMS, "Report of Geology of Laurentian Area to North of Island of Montreal," *Ann. Rept. Geol. Surv. of Canada*, Vol. VIII, J, p. 139, 1896.

STRUCTURE AND ORIGIN OF THE MONTEREGIAN HILLS.

The question of the mutual relations and relative age of the several rock types constituting these hills presents many points of interest. In the case of Mount Royal the essexite which constitutes the greater part of the mountain was the earliest intrusion. When this had become solid the nepheline-syenite broke through it, sending arms into it and catching up detached fragments of the shattered essexite. The same sequence in time is, according to Dresser, to be seen in Shefford Mountain. The basic essexite here forms the earliest intrusion, and was succeeded by the pulaskite and more acid nordmarkite. Mount Johnson, however, presents the two rocks in an entirely different relation. Here, as will be shown later, there was but a single period of intrusion. For although both rocks are present in the mountain, the essexite forms the central portion of the mass and passes over into pulaskite about the periphery of the neck. The mountain thus consists of essexite in its center, surrounded by a zone of pulaskite, the two rocks passing imperceptibly into one another. Mr. Leroy considers it probable that a similar passage takes place in the case of Beloeil mountain, but it is there difficult accurately to determine the relations of the magmas to one another on account of the covering of drift which obscures the contact.

It is thus evident that the two rock types constituting the Monteregian hills are differentiation products of a single magma, the separated magmas, however, in the case of Mount Royal and Shefford having been erupted in succession instead of simultaneously. In connection with the question of differentiation, another noteworthy fact is that the more easterly mountains contain proportionately more syenite and the western hills a greater proportion of the essexite. The bearing of this fact on the character of the differentiation which took place in the subterranean magma basin can be more profitably discussed at a later date when the precise character and relative extent of the intrusions in Yamaska, Rougemont, and Montarville have been determined.

With regard to the structure of these mountains, it may be noted that Logan, who first examined them, refers to them as "intrusive masses breaking through the surrounding Paleozoic strata."[1] They are thus represented in the geological sections of this district contained in the atlas accompanying his report. Ells refers to them simply as "eruptive mountains."[2] The more detailed studies of Shefford and Brome mountains recently carried out by Dresser, however, have led him to consider these two occurrences as uncovered laccolites. Concerning Shefford mountain he says:

> The sedimentary strata which surround the mountain . . . . are found to wrap around the igneous mass of the mountain, mantling it with a hardened contact zone to a height of 300 to 1,000 feet above the surrounding country, according to the direction of glaciation. Above the latter height the mountain rises upward of 200 feet, the summit being capped by an outlier of Trenton slate about a quarter of a mile in extent. This preserves the cleavage, dip, and strike of the similar rock at either side of the mountain and is penetrated by dykes from the underlying igneous rocks. From these facts, together with the absence of tufaceous material and the general arching of the strata around the mountain, it is inferred that Shefford mountain is an uncovered laccolite rather than the denuded neck of a once active volcano.[3]

In Brome mountain also the presence of outlying masses of the surrounding sedimentary series at high levels lying upon the igneous rock of the intrusion "seem to indicate unmistakably that Brome mountain, like Shefford, is an uncovered laccolite and has never been an active volcano."[4]

Mount Johnson, on the contrary, as will be shown, is a typical neck or plug, representing a portion of the conduit through which the magma rose, to fill laccolites above in strata which have long since been swept away by erosion, or to be poured out at the surface at volcanic vents. This is seen by the fact that the flat-lying strata all about it are not arched up, but abut sharply against the igneous core of the mountain and are cut off by it. Being shales, they are of course baked to hornstones, but show no signs of upheaval or tilting. The small size and almost circular cross-section of the mountain are a further indication of this origin; and finally there is conclusive proof that there was a vertical or upward movement of molten rock through the pipe. The mountain has been figured by Professor Davis, in his *Physical Geography*, from one of the author's photographs, as a typical example of a volcanic neck.

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[1] *Geology of Canada*, p. 655.

[2] *Ann. Rept. of Geol. Surv. of Canada*, Vol. VII, J, p. 71.

[3] *American Geologist*, October, 1901, p. 204.

[4] *Geol. Surv. of Canada, Summary Rept. for 1901*, p. 187.

In a recent paper by Buchan[1] the view was put forward that Mount Royal represents the remnant of a denuded laccolite—on the ground that on one side of the mountain, toward the summit, there is an isolated mass of flat-lying, altered Paleozoic limestone, evidently a part of the sedimentary strata of the plain from which the mountain rises. This alone, however, is not sufficient to establish a laccolitic origin, and opposed to such an explanation is the fact that where the strata of the plain are seen along their immediate contact with the intrusion in many places, especially on the eastern and northern side of the mountain, they abut against the intrusive rock and are cut off by it instead of being uptilted, the igneous core of the mountain rising up precipitously like a wall across the truncated edge of the beds. The occurrences of the flat-lying limestone on the side of the mountain referred to above appear to represent the remnant of certain beds, beneath which a portion of the intrusive mass penetrated, after the manner of a laccolite, on one side of the mass. Their existence does not by any means indicate a laccolitic structure for the mountains as a whole, or that the igneous material did not find a vent at the surface, there developing a volcano. In fact, there is evidence in the existence of a remarkable deposit of a breccia-conglomerate in several places around the mountain that it did develop as a volcano and that the materials constituting the deposit in question were ejected from it. A study of this breccia was undertaken last autumn by one of the geological field parties of McGill University, and a description of it, with a discussion of its origin, is now in press and will appear in the *Canadian Record of Science* within the next few weeks. The other four hills have not as yet been studied in sufficient detail to enable any definite statement concerning their structure to be made.

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[1] *Canadian Record of Science*, Vol. VIII (1901), p. 321.

In the Monteregian hills there are thus intrusions of the nature of laccolites, true necks, and probably also of stocks. The age of the intrusions cannot as yet be definitely determined. They are later than the lower Devonian, for some of the dykes connected with Mount Royal cut limestones which belong to the summit of the upper Silurian, while fragments of limestone which are shown by the fossils which they contain to be referable to the lowest beds of the Devonian, occur as inclusions in the volcanic breccia or agglomerate which is found about the flanks of the same mountain. The deeply eroded character of the mountains, however, shows that they are of early date, and it seems most probable that the intrusion took place somewhere in later Paleozoic times.

Having considered in a general way the character of the Monteregian hills as a whole it may be of interest to look somewhat more closely into the structure and petrographical characters of one member of the group which has recently been studied in some detail, namely Mount Johnson.

MOUNT JOHNSON.

Mount Johnson rises from the plain twenty-two miles east-southeast of the city of Montreal, and six miles northeast of the town of St. Johns on the Richelieu river, and twenty-five miles north of the international boundary. The little village of St. Grègoire is situated near its base. The surrounding country is perfectly flat, forming a fertile and well-tilled agricultural district, the nearest mountain being Rougemont, which lies in a northeasterly direction some nine miles distant. In cross-section Mount Johnson is nearly circular. (Fig. 2.) The igneous plug itself has at the base, immediately above the hornstone collar, a somewhat elliptical outline and measures 3,500 feet by 2,500 feet, the longer axis having a direction N 20° E. This gives the

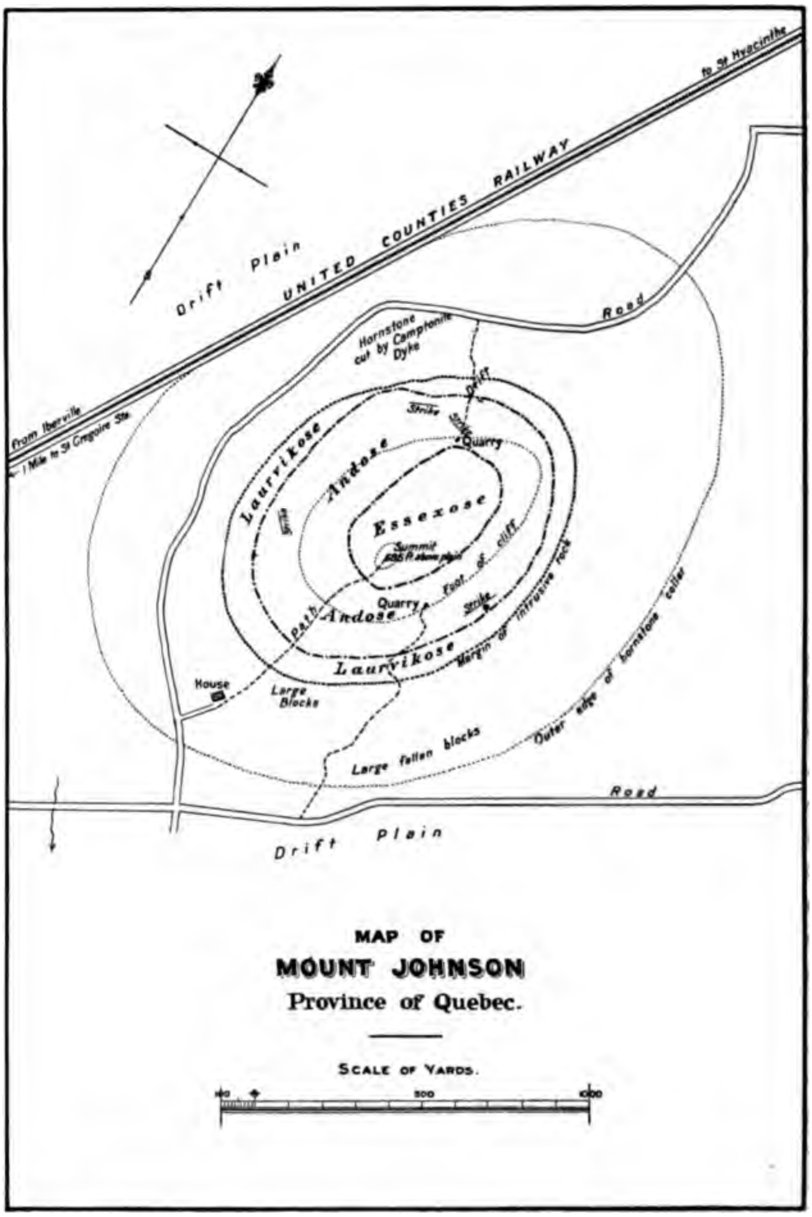
to St Hyacinthe
UNITED COUNTIES RAILWAY
Drift Plain
Road
Hornstone cut by Camptonite Dyke
Drift
Strike
Strike
Quarry
From Iberville
1 Mile to St Gregoire Sta.
Laurvikose
Andose
Strike
Essexose
Summit
685 ft above plain
Foot of cliff
Quarry
Strike
path
Andose
Laurvikose
Margin of intrusive rock
Outer edge of hornstone collar
House
Large Blocks
Large fallen blocks
Road
Drift Plain
MAP OF
MOUNT JOHNSON
Province of Quebec.
SCALE OF YARDS.
100
0
500
1000

FIG. 2.

igneous intrusion an area of .422 of a square mile. The mean of a series of closely concordant aneroid readings, corrected by comparison with barometers at the observatory of McGill University at Montreal, shows that the highest point of the mountain is 685 feet above the main street in the village of St. Grègoire opposite the church, that is, above the surrounding plain, or 875 feet above sea-level, the plain here having an elevation above sea-level of 190 feet. It has a somewhat dome-like outline and forms a very striking feature in the landscape. The slope on the southern side is steep, in places precipitous, while to the north it is more gentle. The accompanying photograph (Fig. 3), taken from the railway station near St. Grègoire, which is about a mile and a quarter distant from the mountain in a direction approximately southwest, shows this profile, as well as the little notch near the summit caused by a ravine which passes down the side.

At the foot of the mountain, more especially on its southern, southeastern, and southwestern sides, are numbers of large blocks which have fallen from the steep upper slopes and extend out from the foot; on the southern is a gently sloping, terraced platform of drift which in part buries these great blocks, forming a "tail" probably due to the drift accumulating here on the lee side of the mountain during the ice movements in the glacial age. This drift, however, has been in part at least reassorted by wave-action during the period of depression which in this region followed the glacial age and during which the sea covered the plain to a depth of several hundred feet at least, as shown by the high level terraces with shell banks on the slopes of Mount Royal. On the plain about the mountain no rock exposures are seen. A mantle of drift covers it, and numerous erratic blocks and bowlders are scattered about. These are largely gneisses from the Laurentian highlands, but some of them are plutonic rocks from other hills of the Monteregian group. The plain about Mount Johnson is, however, stated by Ells, who has examined this district, to be underlain "presumably" by rocks of the Utica-Lorraine division of the Lower Silurian.

On ascending the mountain the first rock which is exposed above the drift mantle is a very fine-grained dark hornstone, uniform in character and lying in undisturbed horizontal beds. It can be seen at intervals all around the base of the mountain, forming a sort of collar, and is undoubtedly a shale such as that usually constituting the Utica formation, here however altered by its proximity to the intrusion. This shale wherever seen lies flat and abuts against the igneous rock of the intrusion, being cut sharply off by it, but not tilted or upturned. The upper limit of the shale is shown in the accompanying photograph of the mountain.

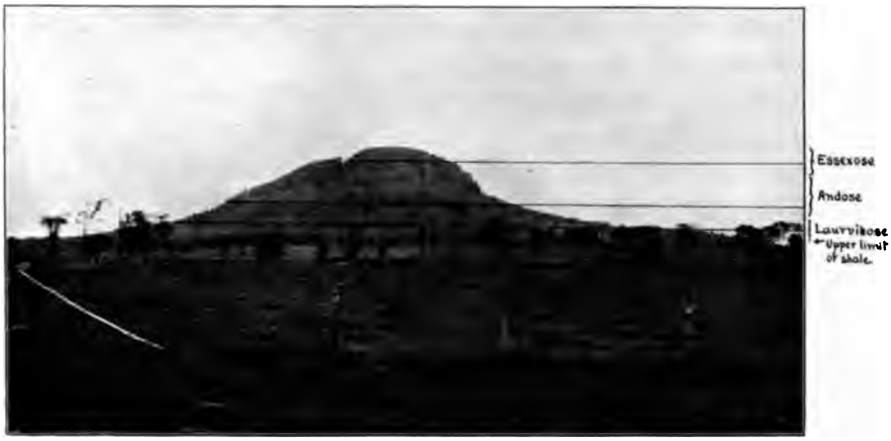

FIG. 3.—Mount Johnson, as seen from the southwest, showing limits of the several rock types composing the mountain.

The mountain above this hornstone collar is made up exclusively of igneous material, which presents a most striking and beautiful instance of differentiation.

Immediately above the hornstone collar, and in contact with it, is a coarse-grained and highly feldspathic syenite, light buff in color, of the pulaskite type. This, as the mountain is scaled, passes rather abruptly into a dark-colored rock with large porphyritic white feldspars, which in its turn loses its porphyritic character and passes into a coarse-grained essexite which constitutes the mass of the hill and which becomes at the summit finer in grain, richer in pyroxene and often holding a little olivine. No sharp lines can be drawn between these several rocks; one passes gradually into the other, the whole constituting one intrusive unit. The approximate limits of these several rock species are shown in the accompanying map (Fig. 2) and photograph (Fig. 3) of the mountain, it being impossible sharply to delimit the several species, seeing that they pass into one another. The mass therefore becomes progressively more basic as we pass from the margin of the intrusion to its center. The two chief rock types are the pulaskite and the essexite which will be separately considered. The essexite, being the more abundant rock and one presenting a greater complexity in mineralogical composition, may be first described.

ESSEXITE.—The rock is dark in color and rather coarse in grain, and although holocrystalline usually presents a more or less marked fluidal arrangement of the constituents. This is especially marked in the zone of transition between the essexite and pulaskite, owing to the presence there of the large feldspar phenocysts which, being arranged with their longer axes parallel to the direction of flow, serve to accentuate this structure. The finer-grained variety forming the summit of the mountain is more massive in character and does not exhibit the fluidal arrangement of constituents. Under the microscope the rock is seen to be composed of the following minerals: hornblende, pyroxene, biotite, olivine, plagioclase, nepheline, sodalite, apatite, magnetite, sphene, and in some cases a very small amount of orthoclase.

There is a marked tendency on the part of all the constituents to assume an idiomorphic development. The long lath-shaped plagioclases and large hornblende individuals have an approximately parallel arrangement, and between these lie the other iron-magnesia constituents with the smaller plagioclase individuals, the nepheline and the other components of the rock. These interstitial constituents do not differ greatly in size from the others and show the same tendency to a parallel arrangement.

Hornblende.—Although almost every thin section of the rock contains not only hornblende, but pyroxene and biotite also, their relative proportion varies considerably. The hornblende is distinctly the most abundant, except in the finer-grained variety forming the summit of the mountain in which it is distinctly subordinate in amount to both pyroxene and mica. It is deep brown in color and is sometimes hypidiomorphic in its development, but often occurs with perfect crystalline form, showing the prismatic and the orthopinacoidal faces. Its extinction is larger than is usual in brown hornblendes, judging from the recorded instances, reaching 20°. It possesses a strong pleochroism as follows:

$\mathfrak{a}$ = pale yellowish-brown.
$\mathfrak{b}$ = deep-brown.
$\mathfrak{c}$ = very deep-brown.
Absorption = $\mathfrak{c} \geqslant \mathfrak{b} > \mathfrak{a}$.

It is often twinned parallel to $\infty P \overline{\infty}$ or to a steep orthodome, and sometimes presents a faint zonal structure, marked by a slight difference in extinction of the several zones indicating a slight change in composition as growth proceeded, and occasionally a greenish tint is noticeable about the margin of the individual. It sometimes holds inclusions of magnetite and is often intergrown with the pyroxene. In the essexite from one place on the south side of the mountain, the hornblende was found free from inclusions, and practically free from the pyroxene which is usually so intimately associated with it. From this locality a quantity of the hornblende was obtained in a state of perfect purity through repeated separations by means of Klein's solution, all grains of foreign mineral still remaining being finally removed by picking them out by hand with the aid of a powerful lens. The pure material thus obtained was analyzed by Professor Norton Evans, of the McGill University, every precaution to secure accuracy being observed and especial care being taken to effect a complete separation of the magnesia from the alumina by the repeated precipitation of the latter. The water was estimated by a direct determination. The results of the analysis are given below, together with those of several other hornblendes of similar composition which have been added for purposes of comparison:

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
SiO_2	38.633	39.75	40.15	40.14	41.35	39.16
TiO_2	5.035	5.40	5.21	4.26	4.97	.....
Al_2O_3	11.974	15.00	14.34	14.30	13.48	14.39
Fe_2O_3	3.903	7.86	7.80	7.07	5.14	12.42
FeO	11.523	2.89	4.53	6.27	10.33	5.85
MnO	0.729	.....	.....	0.21	.....	1.50
MgO	10.200	14.16	13.14	11.62	11.44	10.52
CaO	12.807	12.97	11.75	12.00	10.93	11.18
Na_2O	3.139	1.92	2.31	2.22	2.10	2.48
K_2O	1.489	1.61	1.14	1.35	0.62	2.01
H_2O	0.330	.....	.....	.....	0.48	0.39
	99.762	101.56	100.37	99.44	100.84	99.90

No. 1. Hornblende. From the essexite of Mount Johnson, province of Quebec, Canada.
No. 2. Hornblende. From Bohemian Mittelgebirge.
No. 3. Hornblende. From tuff of hornblende basalt, Härtlingen, Nassau.
No. 4. Hornblende. Basalt tuff, Hoheberg, near Giessen.
No. 5. Hornblende. From "hornblende diabase," Gräveneck, near Weilburg.
No. 6. Hornblende. Syntagmatite. Jan Mayen.

Analyses Nos. 2 to 6 are taken from Schneider's paper referred to below.

The hornblende thus belongs to the class of basaltic hornblendes, and not to the barkevikites as might be expected. It contains, however, proportionally more of the iron in a ferrous condition, together with somewhat less alumina and a somewhat larger proportion of alkalies than most basaltic hornblendes. The unusually high extinction for a hornblende of this class which it possesses is probably connected with the high content in ferrous iron, since Schneider[1] has shown that the extinction increases with the increase of iron in this state of oxidation.

Pyroxene.—This mineral occurs intimately associated and often intergrown with the hornblende, both minerals frequently holding many inclusions of magnetite and apatite. It is very pale-greenish in color, with no perceptible pleochroism, but with a marked dispersion of the bisectrices. It is usually hypidiomorphic, but is frequently idiomorphic, showing a distinct cleavage parallel to the pinacoids, but usually none parallel to the prismatic faces. It belongs to the variety of diopside-like

[1] "Zur Kenntniss basaltischer Hornblenden," *Zeitschr. für Kryst.*, 1891, p. 579.

augites which occur in rocks of this class. The extinction is high, reaching 45°.

Biotite.—This is deep-brown and almost identical in color with the hornblende and is strongly pleochroic, **c** yellowish-brown, and **a** deep-brown. It occurs intimately associated with the hornblende and augite, and also frequently as a border around the iron ore. While usually present in comparatively small amount, in the finer-grained essexite forming the summit of the mountain it is much more abundant than the hornblende. In this variety of the essexite both the mica and the hornblende often possess a poikilitic structure owing to the presence of numerous inclusions of plagioclase, which mineral also often penetrates the individuals of biotite and hornblende in the form of well-developed crystals.

Olivine.—This species is found in the finer-grained variety of the essexite at the summit of the mountain, and was also observed in the thin sections from the essexite at one point on the east side of the mountain not far from the summit. It is very pale-green in color and occurs as little grains inclosed in the biotite and pyroxene.

Plagioclase.—The plagioclase in the rock has well-developed, lath-like forms and is, almost without exception, excellently twinned according to the albite law. Twinning according to the carlsbad and pericline laws is also very common, occurring in the same individuals which show the albite twinning. The laths of plagioclase can in a few cases be seen to be distinctly twisted, evidently owing to pressure exerted upon them by other crystals during the consolidation of the rock, since the rock was submitted to no dynamic action subsequent to its crystallization.

As before mentioned, all the plagioclase individuals are not of the same dimensions. There are larger laths associated with the large hornblende crystals, and between these are smaller laths. The two sets are not, however, sufficiently well marked to cause the resulting structure to be classed as porphyritic. The plagioclase in the rock is not all of the same composition, but varies somewhat, even in the same hand specimen, ranging from an extremely acid labradorite to an oligoclase. It, however, is chiefly andesine. Its character was determined by a large number of extinction measurements carried out on the albite twins, as well as by Michel-Lévy's method, which can readily be applied owing to the frequency of carlsbad twinning in association with albite twinning. These determinations were extended and checked by a number of specific-gravity determinations and separations by means of Thoulet's solution. The larger plagioclase individuals were found, in the case of the rock on the northeast side of the mountain 320 feet above the plain, to be somewhat more basic than the smaller crystals, having the composition of a basic andesine, while the latter ranged in character from andesine to oligoclase. In this case no feldspar having a specific gravity of over 2.65 was found to be present in the rock. Again in the rock of one of the quarries on the south side of the mountain, the larger feldspars tested by Michel-Lévy's method were found to have the composition of a very acid labradorite, $Ab_1 An_1$. The results of a separation of the constituents of the rock by Thoulet's solution showed that the feldspar was almost all andesine, although it varied from $Ab_1 An_1$ to an oligoclase. A crystal examined by Mr. Wright in Professor Rosenbusch's laboratory gave on P an extinction of 5°–6° and on M about 11°, showing the feldspar to be on the line between andesine and labradorite. A very small amount of orthoclase was also present, forming a subordinate accessory constituent. That there is a variation in composition even in the same individual of plagioclase is indicated in many cases by marked growth rings with different extinctions in the different rings. The smaller plagioclases, although twinned in the same manner as the larger, usually have the twinning developed in a less striking manner. A certain proportion of the smaller grains are also untwinned, but most of these must be identical in character with the twinned feldspar, since the separations show that, while orthoclase is often present, it occurs in only extremely small amount. Dr. Sterry Hunt gives[1] an analysis of the feldspar from the essexite of Mount Johnson (called by him diorite). This is as follows:

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[1] *Geology of Canada*, p. 477.

SiO_2	62.05
Al_2O_3	22.60
Fe_2O_3	.75
CaO	3.96
Na_2O	7.95
K_2O	1.80
Volatile	.80
	99.91

Sp. G.= 2.659.

This feldspar has the specific gravity and general composition of an acid andesine, although the high content of K_2O may possibly indicate the presence of some potash feldspar as an intergrowth.

Nepheline.—This is quite subordinate to the feldspar in amount. It possesses the usual low index of refraction, with extinction parallel to the cleavages, which latter can usually be seen. It is sometimes quite fresh, but at other times is found more or less completely altered to a mineral which occurs as little fibrous bundles, showing strong double refraction and parallel extinction. The fibers usually have a more or less distinctly parallel arrangement. This mineral remains practically unaltered when treated with concentrated hydrochloric acid for twenty minutes, although the nepheline in which it is imbedded is destroyed. It is either muscovite or kaolin. The nepheline is allotriomorphic and occurs chiefly in the corners between the larger crystals of feldspar and other minerals, and is penetrated by them. It is especially abundant in those portions of the rock which are rich in the dark-colored constituents. When occurring in this manner it appears, with the sodalite, to have been the last constituent of the rock to crystallize out. It is usually much more abundant than the sodalite. The nepheline also occurs in places as irregular-shaped lath-like inclusions in the feldspar.

Sodalite is usually, although not invariably, present. It strongly resembles the nepheline in appearance and shows the same alteration product. It is, however, quite isotropic. Like the nepheline, it occurs either in the spaces between the other minerals, cementing them together, or as inclusions in the feldspars.

Apatite.— The abundance of apatite is a distinct feature in this, as in similar rocks occurring elsewhere. It is always present and was the first constituent to crystallize out, being found in the form of perfect hexagonal prisms with double pyramidal terminations imbedded in the iron ore. It also occurs in the sphene as well as in the iron-magnesia constituents, in the nepheline, and also, although much less frequently, in the feldspar. Its large amount is shown by the high percentage of phosphoric acid in the analysis of the rock, 1.23 per cent. Another specimen of the rock in which the phosphoric acid was determined by Dr. B. J. Harrington gave 1.01 per cent. These figures represent 2.79 per cent. and 2.35 per cent. of apatite, respectively. It is usually somewhat turbid from the presence of minute dust-like inclusions.

Magnetite occurs chiefly inclosed in the iron-magnesia constituents, but is occasionally found in the feldspar. It is black, opaque, and highly magnetic, and is usually allotriomorphic, but occasionally presents an approximation to definite crystalline outline. As shown by the calculation of the analysis of the rock, this iron ore contains a considerable percentage of titanic acid.

Sphene is not found in more than one-half of the specimens examined. When present it is not very abundant and usually occurs as well-defined wedge-shaped crystals, often of considerable size.

In the accompanying table analyses are given of the normal essexite which forms the greater part of Mount Johnson, and of the finer-grained olivine-bearing variety of the same rock found at the summit of the mountain. For purposes of comparison there is presented in the same table the analysis of the essexite from Shefford mountain, which belongs to the same Monteregian province, together with analyses of the original essexite from Salem, Mass., and of allied rocks from two other localities. A partial analysis of the transitional rock between the essexite and the pulaskite of Mount Johnson is also given.

For the analysis of the Mount Johnson essexite (No. 1) as well as for that of the associated pulaskite, which is given below, I am indebted to Professor Norton-Evans, while the analysis of the olivine-bearing variety of the essexite (No. 2) was made for me by Mr. M. F. Connor. The methods recommended by Hillebrand and employed in the very accurate, analytical work carried out in the laboratory of the United States Geological Survey were followed by both analysts and every precaution was taken to insure accuracy.

	I	II	III	IV	V	VI
SiO_2	48.85	48.69	53.15	46.99	47.67	50.40
TiO_2	2.47	2.71	1.52	2.92	....	1.17
Al_2O_3	19.38	17.91	17.64	17.94	18 22	....
Fe_2O_3	4.29	3.09	3.10	2.56	3.65	5.58
FeO	4.94	6.41	4.65	7.56	3.85	
$NiO+CoO$	not det.	0.05	not det.	not det.	....	not det.
MnO	0.19	0.15	0.46	trace	0.28	0.77
MgO	2.00	3.06	2.94	3.22	6.35	....
CaO	7.98	7.30	5.66	7.85	8.03	6.77
BaO	....	0.08	0.13	none	....	....
Na_2O	5.44	5.95	5.00	6.35	4.93	6.24
K_2O	1.91	2.56	3.10	2.62	2.97	2.56
P_2O_5	1.23	1.11	0.65	0.94	....	0.09
Cl	not det.	not det.	0.07	....	....	....
H_2O	0.68	0.95	1.10	0.65	3.82	....
Total	99.36	100.02	99.84	99.60	100.15	

I. Normal essexite (andose), Mount Johnson, Quebec.

II. Olivine-bearing essexite (essexose), Mount Johnson, Quebec.

III. Essexite (akerose), Shefford mountain, Quebec, (*American Geologist*, 1901, p. 201), (with $CO_2$0.39 and $SO_3$0.28).

IV. Essexite (essexose), Salem Neck, Salem, Mass. (Washington, JOUR. GEOL., 1899, p. 57).

V. Theralite, Elbow Creek, Crazy mountains, Montana.

VI. Rock forming transition from essexite to pulaskite, Mount Johnson, Quebec. (Partial analysis. The iron present is all calculated as FeO.)

The analyses (Nos. 1 and 2) of the two varieties of the essexite from Mount Johnson can be readily calculated out so as to show the quantitative mineralogical composition of the rocks.

The calculation of the *mode*[1]—or relative proportion of the minerals actually present gives the following result:

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[1] *Quantitative Classification of Igneous Rocks* (*C. I. P. W.*) (University of Chicago Press, 1903), p. 147.

	Essexite (Analysis 1) Mount Johnson		Olivine–Essexite (Analysis 2) Mount Johnson	
Albite	36.75	66.45	29.14	54.79
Anorthite	20.23		13.11	
Orthoclase	9.47		12.54	
Nepheline	3.99	4.77	11.12	11.90
Kaolin	.78		.78	
Pyroxene		6.29		12.22
Hornblende		7.05		2.30
Biotite		2.04		4.08
Olivine		none		2.84
Magnetite	5.68	9.53	3.94	8.41
Ilmenite	3.85		4.47	
Apatite		2.68		2.59
Water (hygr.)		.58		.85
		99.39		99.98

In the case of No. 1 the percentage mineralogical composition given expresses exactly the chemical composition of the rock, except that it requires 0.06 per cent. of FeO in excess of that shown in the analysis. In No. 2 the agreement is complete.

The calculation further demonstrates that the plagioclase in the case of No. 1 is a trifle more basic, and in the case of No. 2 a little more acid, than Ab_2 An_1, which as has been stated, is shown by the optical character and by the specific gravity of the feldspar to represent its average composition in these rocks. The amount of orthoclase recognized in thin sections also appears as mentioned in the description of the rock. The nepheline is in places somewhat altered to a mineral resembling kaolin. The small percentage of kaolin shown by the calculation has therefore been added to the nepheline in extending the table.

In order to fix the position of these rocks in the excellent system of classification recently elaborated by Messrs. Cross, Iddings, Pirsson, and Washington, and to determine the name which should be given to these rocks, if their precise character is to be designated, it is necessary to calculate their *norms*. These have been found to be as follows:

	No. 1		No. 2	
Albite	35.63	69.82	28.62	57.90
Anorthite	23.07		14.23	
Orthoclase	11.12		15.05	
Nepheline		5.40		11.83
Diopside	$34CaO. SiO_2$ — 3.94 $7FeO. SiO_2$ — .92 $27MgO. SiO_2$ — 2.70	7.56	$53 CaO. SiO_2$ — 6.15 $18 FeO. SiO_2$ — 2.38 $35 MgO. SiO_2$ — 3.50	12.03
Olivine	$6 FeO. \frac{1}{2} SiO_2$ — .61 $23 MgO. \frac{1}{2} SiO_2$ — 1.61	2.22	$21 FeO. \frac{1}{2} SiO_2$ — 2.14 $42 MgO. \frac{1}{2} SiO_2$ — 2.94	5.08
Magnetite		6.26		4.41
Ilmenite		4.71		5.01
Apatite		2.68		2.59
Water		.68		.95
			BaO=.08, Excess FeO=.07	.15
		99.33		99.95

No. 1 thus takes the following position in the classification in question:

Class II, dosalane.
Order 5, germanare.
Rang 3, andase.
Subrang 4, andose (grad = polmitic).

Its precise designation would be *nepheline-bearing grano-andose* or in some cases *nepheline-bearing tracho-andose.*

No. 2, however, belongs to the next order and is domalkalic. Its position is as follows:

Class II, dosalane.
Order 6, norgare.
Rang 2, essexase.
Subrang 4, essexose (grad = prepolic).

It would therefore be termed a *nepheline-bearing grano-essexose.* It is therefore seen that the essexite from the central portion of Mount Johnson (No. 2) is practically identical in character and composition with the essexite of the original locality at Salem, Mass. (Analysis IV), while the outer andose is poorer in nepheline and has a somewhat larger proportion of lime as compared with the alkalies.

The proportions of the several minerals present in thin sections of the specimens analyzed were then determined by the system of diametral measurements proposed by Rosiwal.[1] In each case over 500 average diameters were measured instead of 100, which latter number Rosiwal considers to be sufficient. The measurements were, however, confined to a small number of thin sections, namely two in the case of No. 1, and four in the case of No. 2, it being considered advisable to use only sections cut from the actual specimen from which the material for analysis was taken. The results obtained were as follows:

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[1] *Verhd. K. K. Geol. Reichsanst.* (Wien, 1898), p. 143.

	No. 1	No. 2
Feldspar	63.77 per cent.	64.06 per cent.
Nepheline	6.12 "	6.16 "
Pyroxene	9.26 "	13.60 "
Hornblende	8.06 "	1.29 "
Biotite	2.11 "	4.07 "
Olivine	.....	1.40 "
Iron Ore	8.56 "	8.10 "
Apatite	2.12 "	1.29 "
	100.00 "	99.97 "

In the case of No. 1 the results are substantially the same as the calculated *mode* except that there is about 3 per cent. more pyroxene and a correspondingly smaller proportion of feldspar. This relatively high proportion of pyroxene is unusual, the examination of thin sections of the rock for various parts of the mountain showing that, as has been stated above, and as is shown also by the calculation of the *mode* of this specimen, there is usually a preponderance of hornblende over pyroxene. In the case of No. 2 the chief difference between the values measured and the calculated *mode* lies in the relatively higher proportion of feldspar and lower proportion of nepheline in the former. In this rock, however, it is very difficult to distinguish the nepheline from the feldspar in every case. These discrepancies indicate that in applying Rosiwal's method to comparatively coarse-grained rocks such as these, especially if there be any tendency to irregularity in composition a considerable number of thin sections should be employed in order to obtain a true average of the rock as a whole.

For purposes of comparison the analysis of the essexite from Shefford mountain (No. III) has been reduced to its normative form and the position of the rock in the Quantitative classification determined. It is found to be as follows:

Class II, dosalane.
Order 5, germanare.
Rang 3, monzonase.
Subrang 4, akerose (grad = polmitic).

It thus, in composition, occupies, in a manner, a middle place between the essexose and andose of Mount Johnson.

THE PULASKITE.—This soda-syenite which, as above mentioned, forms the outer zone of the mountain, girdling the essexite, is less abundant than the latter and differs greatly from it in appearance. This difference is due chiefly to the fact that it is much lighter in color, being pale-yellow or buff instead of dark-gray, the lighter color being due to the very small proportion of iron-magnesia constituents present and the marked preponderance of the feldspars. The rock also has a more massive structure, the fluidal arrangement of the constituents often met with in the essexite being absent, and it weathers in a somewhat different manner. It possesses, moreover, a species of porphyritic structure, owing to the development of the feldspar in two forms: first, as stout prisms, up to 10^{mm} in diameter, which are light-gray in color and very abundant; and, secondly, in the form of smaller laths of a yellow or buff color which, in association with the iron-magnesia and other constituents, form a sort of groundmass in the rock.

The constituent minerals of the rock are biotite, hornblende, (pyroxene), soda-orthoclase, nepheline, sodalite, apatite, magnetite, and sphene. The darker constituents are identical in character with those occurring in the essexite, and therefore do not require to be described again. Not only are they as a class much less abundant in this pulaskite, but the mica here preponderates, being the prevailing iron-magnesia constituent, while the hornblende is much less abundant and the pyroxene is entirely absent. It may be noted, however, that the hornblende sometimes possesses the greenish tint referred to as occasionally seen about the borders of the hornblende individuals in the essexite, indicating probably that, the pulaskite magma being richer in soda, the hornblende crystallizing out of it has a tendency to take up this element more abundantly.

The feldspar in the pulaskite, as has been mentioned, occurs in part as stout prisms and in part as smaller laths. The latter usually have a somewhat cloudy appearance under the microscope, probably owing to incipient alteration. The larger feldspars are what is commonly described as soda-orthoclase. When examined under the microscope they are seen to be composed of very minute intergrowths of two, and in some cases perhaps even of three, different feldspars — causing them to present between crossed nicols a mottled appearance. These several feldspars have somewhat different indices of refraction, and frequently under a high power, where two are present, one of them can be seen to possess a very minute polysynthetic twinning, while the other is untwinned. The relative proportion of the several feldspars present differs in different grains. The individuals as a whole occasionally present the form of carlsbad twins but usually have the appearance of simple crystals, and Professor Rosenbusch, to whom sections of the work were submitted, considers the feldspars composing them to be microcline, and in part microcline-microperthite, with probably some anorthoclase.

The specific gravity of these phenocrysts was determined in the case of two hand specimens of the pulaskite from different parts of the mountain. In the first of these three specimens of the feldspar were found to have specific gravities of 2.62, 2.609, and 2.603, respectively; while in the second, five specimens of the feldspar were selected and found to have specific gravities lying between orthoclase and albite, which bears out the results of their microscopic study.

The smaller lath-shaped feldspars, although more frequently composed of a single species, often show an intergrowth of two feldspars, as described in the case of the phenocrysts. Separations of the constituents of several species of the rock by means of Thoulet's solution show that these smaller feldspars have a somewhat lower specific gravity than the phenocrysts. Thus, while the specific gravity of the phenocrysts lies between 2.591, and 2.62, that of the smaller feldspars is between 2.591 and 2.56; that is to say, the smaller feldspars approach more nearly to pure orthoclase in composition. They consist chiefly of minute intergrowths of orthoclase with albite, or of either of these with microcline or anorthoclase. No lime-soda feldspar could be recognized in any specimen of the rock.

Nepheline and sodalite.—These minerals are quite subordinate in amount, although they are seen in nearly every thin section. Both minerals present the same characters and occur in the same way as in the essexite, lying chiefly in the corners between the other constituents being penetrated by the latter, but also occurring as inclusions in the feldspar. They are, as a general rule, much altered to the same decomposition product seen in nephe-

	VII	VIII	IX	X	XI	XII
SiO_2	57.44	59.96	65.43	56.45	59.01	60.03
TiO_2	1.97	0.66	0.16	0.29	0.81	.....
Al_2O_3	19.43	19.12	16.96	20.08	18.18	20.76
Fe_2O_3	1.69	1.85	1.55	1.31	1.63	4.01
FeO	2.70	1.73	1.53	4.39	3.65	0.75
MnO	0.25	0.49	0.40	0.09	0.03	trace
MgO	1.16	0.65	0.22	0.63	1.05	0.80
CaO	2.66	2.24	1.36	2.14	2.40	2.62
BaO	not det.	.12	none	.....	.08	.....
Na_2O	6.48	6.98	5.95	5.61	7.03	5.96
K_2O	4.28	4.91	5.36	7.13	5.34	5.48
P_2O_5	0.60	0.14	0.02	0.13	trace	0.07
SO_3	not det.	0.08	0.06	.....	.....	.....
Cl	trace	0.14	0.04	0.43	0.12	.....
H_2O	1.03	1.10	0.82	1.51	0.50	0.59
	99.69	100.17	99.86	100.19	99.98	101.07

VII. Pulaskite (laurvikose), Mount Johnson, Quebec.

VIII. Pulaskite (laurvikose), Shefford mountain, Quebec. (*American Geologist*, 1901, p. 211.)

IX. Nordmarkite (nordmarkose), Shefford mountain, Quebec. (*Ibid.*, 1901, p. 209.)

X. Sodalite syenite, Squarė Butte, Montana (differentiation product of shonkinite).

XI. Umptekite, Red Hill, Moltonboro, New Hampshire.

XII. Pulaskite, Fourche mountain, Arkansas (original locality).

line in the essexite and which is, as has been mentioned, either kaolin or muscovite. Probably both are present.

Apatite is present in considerable amount and in the form of perfect crystals, occurring chiefly in the mica, hornblende, and sphene.

The *iron ore* and *sphene* present the same characters as in the case of the essexite, but the latter mineral is relatively more abundant than in that rock.

An analysis of this pulaskite is given in the accompanying table together with analysis of the pulaskite and the nordmarkite of Shefford mountain described by Dresser. Analysis of three allied rocks from other localities are added for purposes of comparison.

The *mode* of the Mount Johnson pulaskite (No. VII), calculated from the analysis given above, is as follows:

Albite	48.73	74.03
Anorthite	3.06	
Orthoclase and microcline	22.24	
Nepheline		2.56
Kaolin		4.96
Hornblende		5.08
Biotite		6.29
Magnetite	1.86	2.77
Ilmenite	0.91	
Sphene		2.35
Apatite		1.34
Water (hygroscopic)		0.30
		99.68

This proportion of the various minerals expresses exactly the chemical composition of the rock as presented by the analysis, except that a very small excess of silica, amounting to 0.06 per cent., is required.

The calculation shows clearly the fact, ascertained by the study of the thin sections of the rock, that a considerable percentage of sphene is present, a mineral which does not occur at all in the essexite.

The anorthite is probably in combination with the other feldspathic constituents in the form of anorthoclase. The calculation also brings out clearly a point already mentioned, namely, that in this rock the nepheline is much more highly altered than in the essexite, as shown by the amount of kaolin present. This kaolin, however, is not entirely derived from the alteration of the nepheline, but appears as a haze all through the smaller feldspars, and hence in the extension of the results should be assigned in part to the nepheline and in part to the feldspar. It is of course impossible to measure the amount of kaolin present by Rosiwal's method, occurring as it does distributed through the sections in the form of extremely minute individuals. If, however, the amount of nepheline given by the Rosiwal measurement be correct, namely 4.40 per cent.—and this of course includes both the unaltered mineral and that filled with decomposition products—then 1.84 per cent. of the kaolin has been derived from the alteration of the nepheline. There will thus remain 3.12 per cent. of the kaolin which has been derived from and measured up with the feldspar. If this amount be added to the feldspar found by calculation, it will increase the proportion present to 77.15 per cent., which is within 0.09 per cent. of the percentage of feldspar obtained by the Rosiwal measurement.

The *norm* of the pulaskite is found to be as follows:

Albite	50.30	85.61
Anorthite	9.73	
Orthoclase	25.58	
Nepheline		2.56
Olivine $2MgO.SiO_2$	2.03	2.54
Olivine $2FeO.SiO_2$	0.51	
Corundum		0.41
Magnetite		2.55
Ilmenite		3.80
Apatite		1.34
Water		1.03
		99.84

Its position is, therefore, as follows:

Class I, persalane.
Order 5, canadare.
Rang 2, pulaskase.
Subrang 4, laurvikose.

It should thus be termed a *grano-laurvikose* or possibly, in view of its somewhat porphyritic structure, a *granophyro-laurvikose*. The proportions of the several minerals present, or *mode*, as determined by Rosiwal's method were as follows:

Feldspar	77.24	per cent.
Nepheline	4.40	"
Hornblende	5.37	"
Biotite	7.08	"
Iron ore	1.81	"
Sphene	3.29	"
Apatite	.81	"
	100.00	

For purposes of comparison the analysis of the pulaskite (No. VIII) and of the nordmarkite (No. IX) of Shefford mountain were calculated into their respective *norms* and the position of these rocks in the new system of classification determined. The pulaskite (No. VIII) is found to have the following position:

Class I, persalane.
Order 5, canadare.
Rang 2, pulaskase.
Subrang 4, laurvikose.

The nordmarkite (No. IX), however is peralkalic and must be classified as follows:

Class I, persalane.
Order 5, canadare.
Rang 1, nordmarkase.
Subrang 4, nordmarkose.

It, however, lies just on the line between nordmarkose and phlegrose, and might thus be best termed a nordmarkose-phlegrose.

It is thus seen that the rocks from Mount Johnson and from Shefford mountain which, following Rosenbusch's classification, have been called pulaskite, and which in this new scheme of classification are pulaskase, are almost identical in composition with one another and with the Norwegian laurvikite, and the nordmarkite of Shefford mountain is very close in composition to the nordmarkose of the original Scandinavian localitv.

Diagrams showing the composition of these several rocks are presented in Fig. 4.

THE TRANSITIONAL ROCK.—As has been mentioned, there intervenes in Mount Johnson between the pulaskite border and the central mass of essexite a transitional zone consisting of a rock which is dark in color and thus resembles the essexite, but which is characterized by the presence of large porphyritic feldspars sometimes as much as two inches in length, of peculiar form scattered through it and often arranged with their larger axes in the same direction, thus giving a fluidal appearance to the rock. This rock contains a large proportion of the same iron-magnesia minerals, more especially the hornblende, found in the essexite, and passes over gradually into this rock. Its passage into the pulaskite is rather more abrupt and is marked chiefly by the almost entire disappearance of the dark-colored constituents above mentioned. There is, however, a continuous transition or passage from the pulaskite through this intermediate rock into the inner essexite of the mountain.

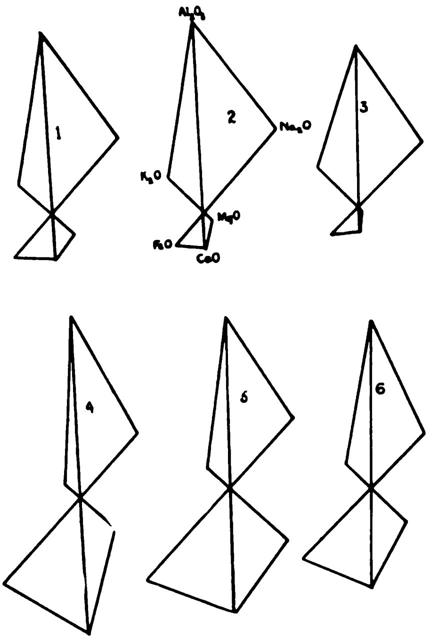

FIG. 4.—Diagrammatic representation of the chemical composition of the several rocks described.

No. 1. Laurvikose — Mount Johnson.
No. 2. Laurvikose — Shefford mountain.
No. 3. Nordmarkose —Shefford mountain.
No. 4. Andose — Mount Johnson.
No. 5. Essexose — Mount Johnson.
No. 6. Andose — Shefford mountain.

This transitional rock is composed of the same minerals as the essexite with the exception of the feldspar, which consists in part of the soda-orthoclase characteristic of the pulaskite, and in part of the plagioclase (in this case oligoclase) which forms the feldspathic element of the essexite. It is thus in mineralogical composition intermediate between these two rocks, although, as above mentioned, being rich in the dark-colored constituents, it more closely resembles the latter.

The large feldspars have frequently a peculiar crystalline form giving to the mineral, when broken across, a perfect hexagonal outline. The six faces represented in this form are apparently T, L, and M. The crystals hold many little inclusions of pyroxene, biotite, hornblende, magnetite, sphene, and nepheline, often regularly arranged so as to give a zonal structure to the feldspar individual. The specific gravity of twelve small fragments of the feldspar of these large crystals, collected from a locality on the southern side of the mountain and as free as possible from all inclusions, was determined. The specific gravity of nine of these lay between 2.59 and 2.607, while that of the other three was between 2.625 and 2.628. This shows the feldspar in the former case to be identical with that of the pulaskite, while in the latter three the specific gravity lies between that of albite and oligoclase. The somewhat greater specific gravity in this case may be due in part to inclusions of other minerals. A separation of the constituents of the rock shows, however, that, as above mentioned, a considerable amount of oligoclase is really present. The feldspar individuals, both great and small, usually show in thin sections the mottled character due to the intergrowth of different species, described in the pulaskite. A partial analysis of a specimen of this intermediate rock, from the south side of the mountain, is given in the accompanying table of analyses (No. VI), on page 265. As will be seen, in chemical composition as well as in mineralogical character, it occupies a position intermediate between the essexite and the pulaskite, occurring on either side of it, thus representing an intermediate zone in which the differentation was not quite completed. It is, however, much more nearly allied to the essexite, being alkalicalcic and dosodic, and although in the absence of a complete analysis or detailed measurements its position in the new classification cannot be determined with absolute certainty, there is very little doubt that it also, like the essexite adjacent to it, is an andose.

DYKES.—A feature in connection with Mount Johnson, and one possibly connected with its somewhat peculiar structure, is the almost entire absence of dykes. These were found only in two places, and in both cases the dykes were small in size. The first of these localities is on the northeastern margin of the intrusion, where the dyke occurs in association with and probably cutting the hornstone. It was found as large angular blocks in the heavy maple bush which here covers the slope of the mountain, but is undoubtedly in place in the immediate vicinity. The rock is very dark gray in color and very fine in grain, and belongs to the camptonites. It has a porphyritic structure, the very numerous phenocrysts consisting of hornblende and pyroxene. The hornblende phenocrysts are deep-brown in color and strongly pleochroic, the mineral being the same basaltic hornblende described in the essexite. The pyroxene of the phenocrysts is pale purplish in color and shows a marked dispersion of the bisectrices. Both minerals have very perfect crystalline forms. The plagioclase of the rock is very basic in character, as shown by its high extension. The rock resembles very closely certain occurrences found on Mount Royal. The size of this dyke is not known, but it probably has not a width of more than a foot or two. The other dykes occur on the southeastern slope of the mountain by the side of the road leading down from the quarries here. At this locality there are four small dykes, the largest only a foot in width, cutting the essexite. These are all very fine in grain and much decomposed, but represent two varieties of rock. Two of the smallest are composed of a camptonite consisting of a groundmass of brownish hornblende and plagioclase, with lath-shaped plagioclase phenocrysts. The other two dykes consist of a rusty weathering rock, made up of feldspar laths and a mass of pseudomorphs of limonite after some prismatic mineral, probably either ægerin or arfvedsonite. Professor Rosenbusch considers it to be a highly altered tinğuaite or sölvsbergite, probably the latter.

The several dykes, while small and unimportant in themselves, are of interest in that they present the petrographical types regularly associated with the alkaline rich intrusions of the class represented in Mount Johnson.

The Structure of Mount Johnson.—The structure of the mountain and the character of the rocks composing it also throw some light on the question as to where the differentiation took place. In course of conversation with the foreman of one of the quarries in the essexite on the flank of the mountain, the writer was informed by him that Mount Johnson consisted of three layers of horizontal rock; a fine-grained one on top, below which was the coarser-grained rock of the quarry, and beneath this a spotted variety. Each of these layers, he considered, went through the mountain horizontally and could be seen outcropping at their respective levels on every side. The three rocks referred to were, as will be recognized, the fine-grained essexose, the andose, and the transitional rock below the latter, respectively. The pulaskite zone he had not noticed, it being at the base of the mountain and in many places more or less covered with fallen blocks and talus. If this were the true interpretation of the structure, the mountain would have to be considered as the rem-

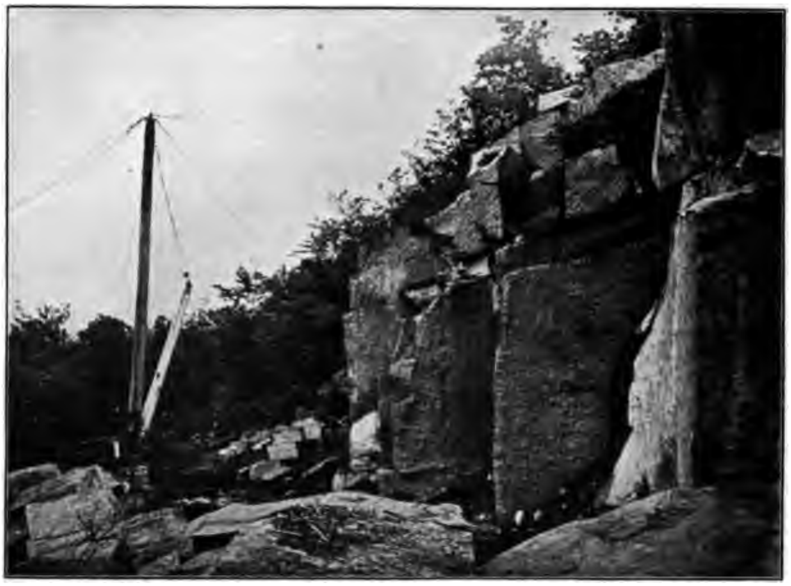

FIG. 5.—Quarry in andose, Mount Johnson, showing vertical flow structure on right.

nant of a laccolite which had been intruded between the horizontal Silurian strata and which had subsequently been almost entirely removed by peripheral denudation. This has been shown to be the true explanation of the origin of some of the occurrences, formerly supposed to be intrusive stocks, in the western portion of the United States, and it was at first considered as a possible explanation of the origin of Mount Johnson. A careful examination of the mountain, however, shows that such an explanation of its origin is untenable, and that it is a true neck, due to the filling up of a nearly circular perforation in the horizontal strata of the plain, by an upward moving magma.

The evidence of this is to be found in the direction of the banding or fluidal arrangement of the crystals in the essexite already referred to and shown in Fig. 5. This fluidal arrangement is seen in most large exposures of the essexite and with especial distinctness in the great faces of this rock exposed in the quarries on the mountain side, and it is always vertical, showing that the movement of the rock was upward through the pipe, and not outward and horizontally over the pulaskite, as it would have been in the case of a laccolite. Furthermore, in several cases when the fluidal arrangement is very distinct and has a somewhat banded character, as shown in Fig. 6, due to the alternation of somewhat more feldspathic portions of the rock with others richer in iron-magnesia constituents, a strike can be made out on horizontal surfaces, and this strike curves around the mountain, following its marginal outline, as shown in the map, Fig. 2.

It is thus clear that Mount Johnson is a neck in its most typical form. A cross-section of the mountain is shown in Fig. 7. The opening occupied by the intrusion was in all probability formed by the perforation of the horizontal shales at this point by the explosive action of the steam and vapors preceding the eruption proper, as it presents exactly the features reproduced by Daubrée in his highly suggestive experiments on the penetrating action of exploding gases. It is, in fact, what he terms a *diatrème*.

Des perforations aussi remarkables, tant par leurs formes que par les communications qu'elles ont établies avec les profondeurs du sol, constituent, parmi les cassures terrestres, un type assez nettement charactérisé pour mériter d'être distingué par une dénomination précise et cosmopolite. Le nom de diatrème rapelle l'origine probable de ces trouées naturelles, véritables *tunnels verticaux*, qui se rattachent souvent, comme un incident particulier, aux cassures linéaires, diaclases et paraclases.[1]

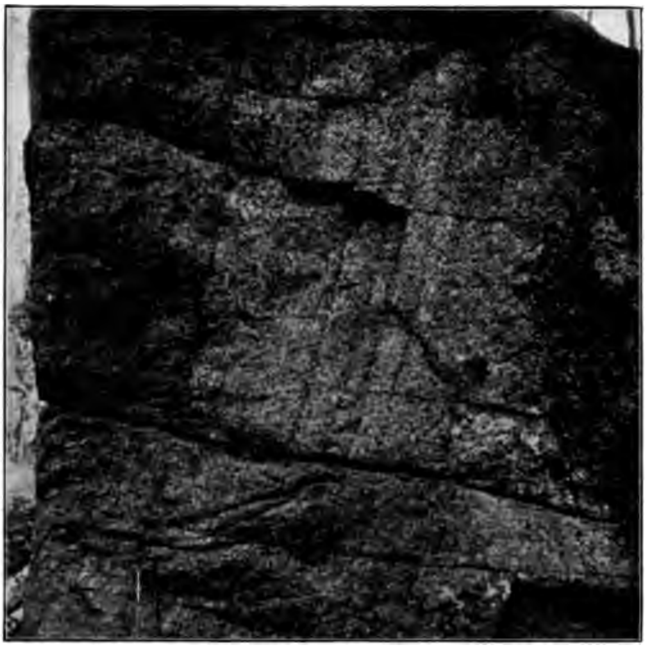

FIG. 6.—Andose in quarry on Mount Johnson, showing vertical flow structure.

The occurrence is one which presents a close resemblance to the remarkable volcanic necks recently described by Sir Archibald Geikie[2] in East Fife, and also to those described by Branco,[3] in Würtemberg. Mount Johnson, however, is a neck occurring in an area which has undergone much more extensive denudation since the time of the intrusion than in the cases above mentioned, and as a consequence of this the fragmental material which fills some, although not all of the necks referred to above, has been entirely swept away.

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[1] "Recherches expérimentales sur le rôle possible des gaz à hautes températures doués de très fortes pressions, etc.," *Bull. de la Soc. Géol. de France*, 3e série, tome XIX (1891), p. 328.

[2] *The Volcanic Necks of East Fife.* Glasgow: Hedderwich & Sons.

[3] *Schwabens 125 Vulcan-Embryonen und deren tufferfüllte Ausbruchsröhren das grösste Gebiet ehemaliger Maare auf der Erde.* Tübingen, 1894.

In view of the fact, then, that Mount Johnson is a neck or pipe of comparatively small sectional area, in which the differentiation is very complete, but in which the magma did not remain at rest, but was not long prior to final consolidation, moving upward, it seems improbable that the marked differentiation of the magma into the several varieties described in this paper took place while the magma was in the pipe itself. The evidence points rather to the differentiation of the mass having already taken place in the reservoir of molten rock beneath, which was tapped by the pipe. If this be the case, it would seem that the upper and more acid portion of the magma, represented by the lighter pulaskite, had collected in the upper portion of the reservoir, and that the essexite formed a lower, more basic, and heavier stratum or part. When the passage to the surface was opened up, the pulaskite would first rise in it and, after a more or less long-continued flow, being followed by the essexite, would be pressed toward the circumference of the pipe, the more basic rock occupying the central portion of the passage, and the most basic variety, originally lower, would be found in the central axis of the neck. The fact that, while the essexite forms the mass of the intrusion, there is a zone of pulaskite about it, would seem to indicate that there had not been at this center of volcanic activity any very protracted outpouring of the essexite, since, had this been the case, it would seem probable

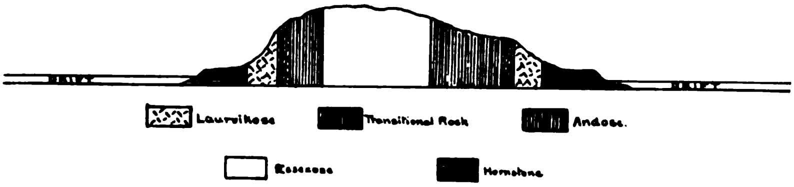

FIG. 7.— Diagrammatic cross-section of Mount Johnson, showing the relation of the several rock types.

that the pipe would have in time been cleared of the earlier pulaskite magma.

The interesting question of the succession of the eruption of the several magmas in this petrographical province, as well as the causes of their differentiation, can be more profitably discussed when the other centers of eruption have been more thoroughly studied. It is interesting to note the cumulative evidence in favor of differentiation as an explanation of the origin of these and similar groups of rocks, arising not only from the repeated association of the various members of the group at many centers in a single area like that described in the present paper, but also at centers widely separated from one another in different parts of the world. The occurrences described by Ramsay[1] in the Kola peninsula may be especially noted in this connection as closely allied to those of the Monteregian hills, a soda-syenite (umptekite) occurring about the margin of an intrusion of the nepheline-syenite which constitutes the *massive*, while theralite is also found as a differentiation product of the same intrusion.

The author desires to acknowledge his indebtedness in connection with this investigation to Miss Rosalind Watson, of Victoria, B. C., who, when a student at this university began the study of Mount Johnson; also to Professor Rosenbusch, Professor Iddings, and Professor C. H. McLeod for valuable aid during the course of the work.

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[1] *Das Nephelinsyenitgebiet auf der Halbinsel Kola.* Fennia 11, No. 2. Helsingfors, 1894.

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PAPERS FROM THE DEPARTMENT

OF

GEOLOGY.

No. 15.—THE LAURENTIAN PENEPLAIN.

BY

ALFRED W. G. WILSON, PH.D.

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THE LAURENTIAN PENEPLAIN.

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INTRODUCTION.

THE late director of the Geological Survey of Canada, Dr. George M. Dawson, in his address before the Geological Section of the British Association, at the Toronto meeting in 1897, mentioned, in passing, that the topographic features of the Archæan areas of North America were those of a peneplain. During the past seven summers the writer has had the opportunity of studying in more or less detail considerable areas around the southern portion of this Archæan region extending from Lake Champlain in the east to the Hudson Bay divide in central Keewatin. In a paper published two years ago (41)[1] attention was drawn to some of the geographic features of the southern margin of the Archæan belt within central Ontario. In the present paper, with the aid of the numerous accounts of travels and reports of explorations in various parts of these Archæan regions, these studies have been extended to the greater areas of central and eastern Canada

The purpose of the present paper is, primarily, to draw attention to the physiographic unit, the Laurentian Peneplain,[2] and to present a brief picture of its more salient features; and, secondly, to outline a few of the almost endless variety of geologic and geographic problems which the Canadian shield presents. Many of these problems, in the present state of our knowledge of the vast area here under discussion, are insolvable; many perhaps will never be solved; but none the less it is interesting to review the work already done and to consider that which lies before us.

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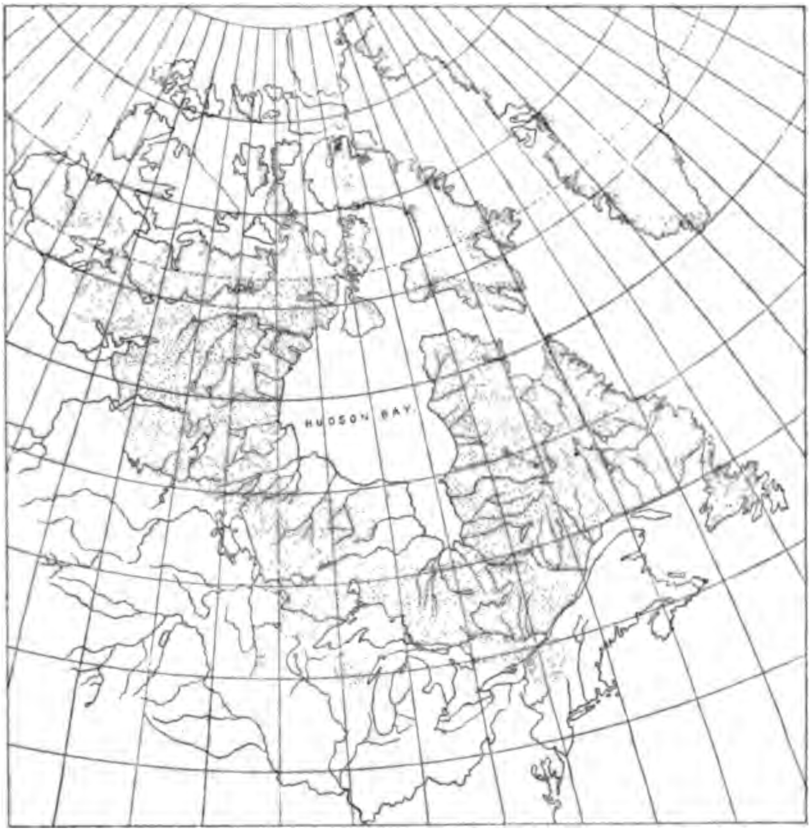
[1] The number refers to the article listed with corresponding number at the end of this paper. A following number indicates the page reference to the article in question.

[2] The adjective "Laurentian" is here applied to this, the largest peneplain developed in Canada, to distinguish this topographic unit from others of a similar type also found in Canada or in the adjacent parts of the United States. For example, we have the Atlantic Coast Peneplain, parts of which, under the title of the New England Peneplain, and the Acadian Peneplain have been described by Davis and Daly respectively; the Tertiary Peneplain of British Columbia has been briefly referred to by Dr. Dawson, and the Peneplain of the Yukon basin has recently been described by H. C. SPENCER, *G. S. A.*, May, 1903. The relations of these minor plains to the greater area here under discussion are not yet definitely established. As will be shown in the succeeding paragraphs, the Laurentian Peneplain itself is not a single plain, but rather is made up of a series of facets intersecting at very low angles, three of which are distinguishable south of the main divide, so that there are probably at least five facets, and perhaps more. It has not been deemed advisable at present to suggest names for these facets.



Sketch map to show the area included by the Laurentian Peneplain. The peneplain area is shaded.

It is not proposed in the present paper to enter upon any discussion of the strictly geologic problems offered by the rocks of the area—such as a consideration of the stratigraphy, origin, and relations of the metamorphic and igneous rocks of the great Archæan complex.

THE CANADIAN OLDLAND.

In its general features eastern North America presents in a most striking manner and on a large scale what may be regarded as a typical development of physiographic forms characteristic of a belted ancient coastal plain centered around an oldland area. The Canadian shield of Suess, the area whose general physiographic features are to be more particularly described and discussed in the succeeding pages of this paper, marks the site of the oldland area from which the materials of the later sedimentary deposits were derived. A reference to the accompanying sketch map (inset) will show the general U form of this oldland area, which extends from Coronation Gulf in the extreme northwest, southward around Hudson Bay and northward through Labrador to Baffin Land and beyond. Its width varies from nearly a thousand miles in Labrador to about two hundred miles in the country southwest of James Bay.

Bordering the oldland on its convex side, and extending from the island of Anticosti in the Gulf of the St. Lawrence westward and northward as far as the Arctic circle, and probably beyond, we have a series of land forms presenting on the grandest scale the general features of an ancient belted coastal plain, in its present aspect much modified, it is true, from normal form —a modification probably due to the operation of relatively recent processes, differential uplift, and glacial action. The belted coastal-plain features are best preserved in the region of the Great Lakes. The most prominent topographic feature of this costal plain is the Niagara cuesta, which can be traced with varying expression from near Rochester, on the south shore of Lake Ontario, westward as far as the state of Wisconsin, beyond which it disappears for a time beneath the drift, but reappears to the west of Lake Winnipeg. Lakes Erie, Huron, Michigan, Manitoba, and Winnipegosis are situated upon the outer lowland;

Lake Ontario, Georgian Bay, Green Bay, and Lake Winnipeg lie upon the inner lowland in front of the cuesta. Lake Superior lies in a depression away from both lowland and cuesta. The portion of the ancient coastal plain in the vicinity of the Great Lakes presents in general aspect and in its present attitude the normal features of such a plain, with numerous drainage modifications due largely to differential uplift and glacial ice action. The portion of the plain which lies west of the oldland area is at

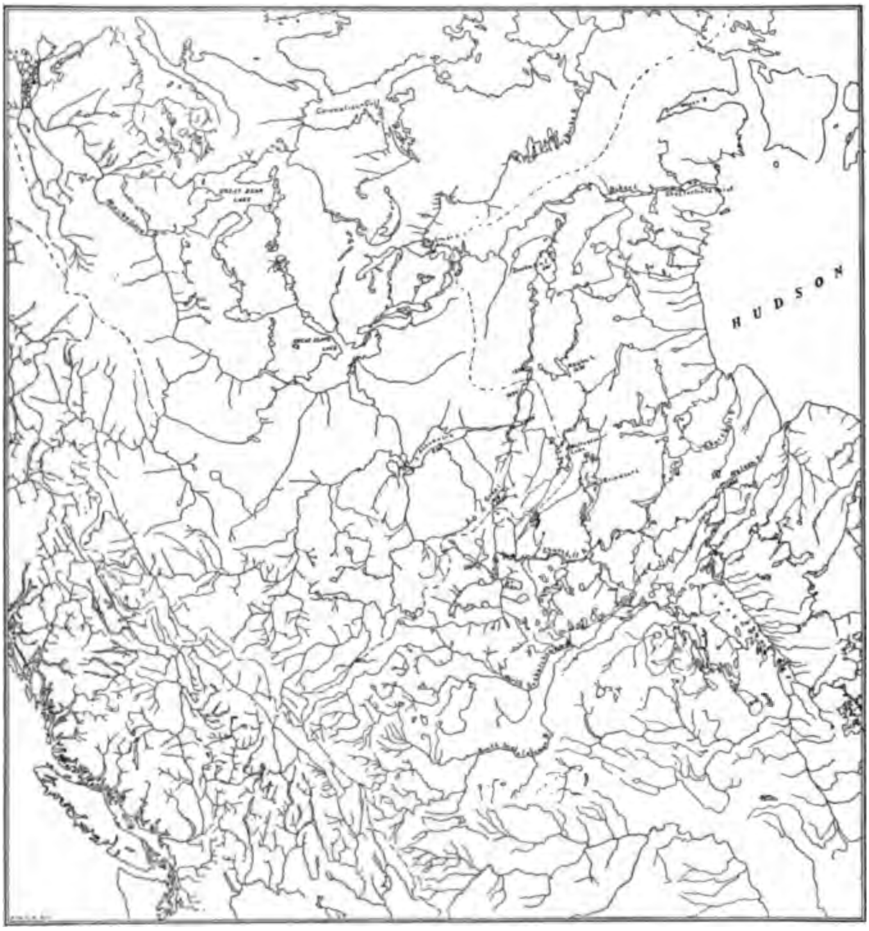


FIG. 1.—Sketch map of the Laurentian Peneplain and the country adjacent—west and southwest of Hudson Bay.

present in such an attitude that practically all the streams flow against the dip of the rocks—a direction opposite to that normally found on a belted coastal plain—a modification in this case apparently due to the uplift of the Cordilleran system on the west.

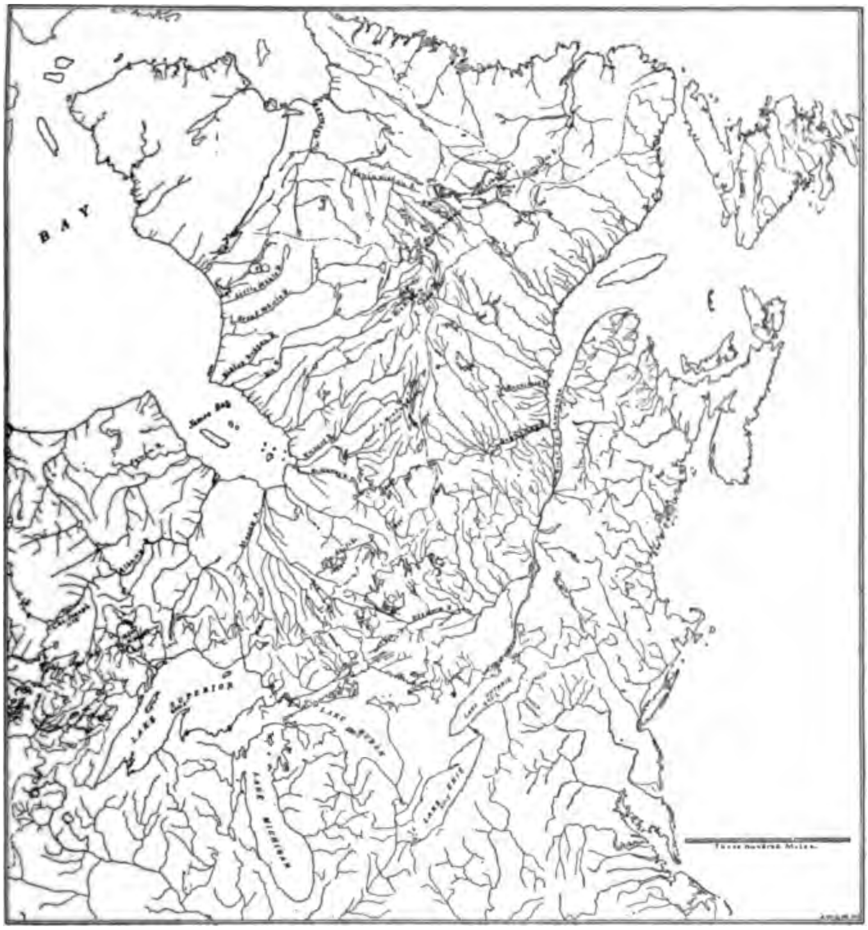


FIG. 1.—Sketch map of the Laurentian Peneplain and the country adjacent—south, southeast, and east of Hudson Bay.

On the southeast side of the oldland the valley of the St. Lawrence lies on a lowland cut on Paleozoic sediments, and shows at the extreme west in the valley of the Ottawa River, and at the east in the Mingan Islands and the Island of Anticosti, typical cuestas with inner and outer lowlands. In the central parts, in the vicinity of Montreal, the relation of the plain to the oldland areas, which stand boldly above it on either side, suggests that here the Paleozoic sediments may have been deposited in a pre-Paleozoic depression of the graben type. The well-known Monteregian hills, the stubs of post-Devonian volcanoes, form prominent buttes rising to a considerable elevation above the level of the St. Lawrence lowland.

On the concave side of the oldland area we find traces of an ancient belted coastal plain, convex southward, but for the most part its features are buried beneath the deposits which form the recent Hudson Bay coastal plain.

EXPLORATION AND SURVEYS.

The Laurentian Peneplain extends through about fifty-eight degrees of longitude and about twenty-three degrees of latitude, covering in all an area of over two million square miles. During the ten centuries that have elapsed since the first daring Norse mariner landed on its eastern shore, many explorers have traveled along the margins of the area, and not a few have traversed it in diverse directions. The early explorers, repelled by the bold and forbidding coast formed by the eastern edge of the uplifted peneplain, along the northwest shore of the Gulf and River St. Lawrence, chose rather the easy route offered by the free navigation of the great river, and penetrated to the heart of the continent and to the more inviting areas lying to the south of the great Archæan belt, long before traverses were made across the peneplain itself. At a later period the active searches instituted to discover a short route to China led to the discovery of Hudson Bay. The continued search for the northwest passage and the attractions offered by the profits of the fur trade resulted in the exploration of portions of the coasts of this inland sea, and in the establishment on its shores, more than two hundred years ago, of trading posts, some of which are still in existence at the present day. In the interests of the fur trade many traverses of the district were made by the employees of the great trading companies, both northward from the early French settlements and southward and westward from the English posts on Hudson Bay. Records of some of these exploratory journeys and records of the travels of the Jesuit missionaries are still extant. Later explorations, incident to the continued search for a northwest passage from Hudson Bay, led several parties across the far northwest portion of the area. Until quite recently the imperfect records of these travelers constituted the only available accounts of large areas of the interior.

The period of active geographic and geologic investigation of this region really began about fifty years ago with Logan's historic work on the geology of the Archæan districts north of the Ottawa River. Since that time more or less systematic geographic and geologic explorations have been carried on, chiefly by the Geological Survey of Canada, but in part by the Topographic Survey's branch of the Department of the Interior at Ottawa. At present we have at least a general knowledge of the main geographic features of the Laurentian Peneplain, although much still remains to be done.

The information used in the present paper, outside that from the writer's personal observations, has been derived chiefly from the reports of the explorations of A. P. Low in Labrador, of Dr. Robert Bell and Dr. A. E. Barlow in the districts to the south and southwest of James Bay, and of J. B. Tyrrell, and J. W. Tyrrell in the country to the east of Hudson Bay. In the papers by A. P. Low, J. B. Tyrrell, J. W. Tyrrell, and Dr. George M. Dawson, to which reference is made below, nearly complete bibliographies will be found dealing with the literature of the subject. It does not seem necessary to reproduce the bibliography here.

The writer is indebted to Mr. A. P. Low, of the Geological Survey Department, Ottawa, for some suggestions to which due reference is made in the text, and also for a number of photographs from central Labrador, from which Figs. 2, 3, 4, 5 and 13 were prepared. He wishes also to acknowledge his indebtedness to Dr. F. D. Adams, of McGill University, Montreal, and to Bailey Willis, of the U. S. Geological Survey, for critical readings of portions of the manuscript of this paper. To Dr.

Adams also the author is indebted for the photographs from which Figs. 6, 7 and 8 were prepared. He has also to acknowledge the kindness of Mr. James A. Smart, deputy minister of the interior, from whom the photographs to prepare Figs. 9, 10, 11, and 12 were obtained.

The original photographs from which the figures were made are deposited in the Collection of Geological Photographs of McGill University, Montreal.

PHYSIOGRAPHIC CONTROLS.

One of the most interesting problems for study presented by the Laurentian Peneplain is the control which the type of topography here developed has had upon the occupation and exploration of the region. Stretching, as it does, from the frozen Arctic to the temperate regions of central Ontario, and from the ocean border on the east to the mid-continental region of the great plains on the west, in its different parts it presents many phases of the operation of climatic controls, which affect its flora, its fauna, and its human occupation.

The uplands of Labrador and the far northwest of the region (north Keewatin, and northeast Mackenzie) are devoid of trees, the vegetation being confined to the lower orders of plants. Next southward we find the belt of conifers stretching all across the region from Hamilton Inlet to northwest of Great Slave Lake, the trees increasing in size and variety with decrease of latitude. In the central parts deciduous trees abound. Although, in general, throughout the region we find uniformity of features, in structure and development there is a great diversity of detail. The enormous number of the lakes and streams, the widespread distribution of the forests, the general uniformity of the topography, and the climatic characteristics of the region, have all contributed to make it the home of those animals whose flesh is valuable for food, and whose pelts are valuable for clothing or (secondarily) as an article of commerce. The remarkably even character of the region, the character of the flora, and the protection offered by climatic conditions even now make possible the existence of those vast herds of caribou (comparable to the herds of buffalo which roamed the great plains of the West until after the advent of the destructive white man) which at present roam over the barren grounds (see Fig. 8). The character of the country makes the continued existence of the fur-bearing and game animals possible. The widespread distribution of these animals, the chief support of the inhabitants, has led to the scattering of the people over the whole area, and to the development of more or less nomadic habits and customs.

The Indian inhabitants of the region, living chiefly on the products of the chase, have here, from time immemorial, found their hunting-grounds. The numerous lakes and streams, then as now, were the only lines of communication in all that vast area. Their distribution through all parts of it, and the comparative ease with which traverses from one body of water to the next can be made, enabled these people to wander unimpeded over the whole region. The customs of these people, in the several parts of the area, differ but little; in language there are greater differences, but over very large areas the speech is the same. Probably nowhere else, over so large an area, have scattered communities been found which have retained so well their communal characteristics. In language, customs, and culture they differ greatly from the various tribes found in the mountainous districts of British Columbia. In some of the still unexplored parts of the region there are Indians who have never yet seen a white man, unless perhaps some half-breed trader.

On the other hand, to the average white man, with his different modes of living, the region with its exceedingly limited agricultural possibilities, has always been inhospitable. He has displaced the Indian in the fertile plain regions which border the peneplain area to the south and west. The last remnants of some of these displaced tribes still survive upon these uplands, and still eke out a more or less precarious existence on the products of the chase. To the white man, however, the region offers other inducements which lead to the temporary occupation of local areas. The degradation which produced the peneplain has not only made possible the widespread forests, but has also exposed valuable mineral deposits that otherwise would not have been accessible. The region is thus of the utmost importance as the source of almost a world's supply of timber, and of the products of the mine, more particularly iron ore.

The journeys of the early explorers across the region were possible because of the character of its topographic features. They were undertaken by the early missionaries almost always, and by the fur-traders, frequently, to visit the wandering Indians scattered throughout the region. The fur-traders often undertook journeys solely for the pupose of hunting. The stories of the travels of these early missionaries as told by Parkman and others, and the history of the great fur companies, incidents of which form the historic foundation of many tales, afford some of the most fascinating chapters in the history of Canada, and in the study of the physiographic controls of this region. The early exploration of the eastern, central, and southern part of the western arm of the area were largely made by the early Jesuit missionaries and the employees of the great trading companies. The exploration of the far northwest, on the other hand, with the exception of three years' adventurous wanderings of Hearne, an employee of the Hudson Bay Company, were merely incidental to the continued search for a possible northwest passage.

The climatic conditions of the far northwest; and the absence of soil in any considerable amount from the Labrador areas and the country just north and west of Lake Superior, means that these regions will always be shunned by the majority of white men in search of a permanent abode. There are, however, considerable areas where there is a good soil cover, generally of fine glacial or lacustrine clays and sands, which are habitable and lie within the wheat belt. The largest of these lies between James Bay and the Lake Superior divide. Smaller areas, now partly occupied, occur in the vicinity of Lakes Temiscaming and St. John. The region is, however, one of great promise in another respect. Under progressive governmental control, and the competent supervision of trained forest engineers, it could be made an immense permanent forest reserve, a source of timber for many centuries to come. At present the timber resources are being rapidly exhausted, and practically no provision is made for the restoration of the forests.

Until the work of scientific exploration was undertaken by the government, little valuable information about the resources of the area was available, although much had been gathered in the preceding two hundred years by the employees of the great trading companies. This information was, however, kept buried in their archives, since the policy of these companies required that the richness and extent of their domain be kept secret as much as possible.

The beauty and diversity of the scenery, the innumerable lakes and waterways, the fascination of the dense forests, the salubrity of the upland climate during the summer season, and the opportunities afforded for exercising the innate hunting instincts present in nearly every man, will more and more make the accessible portions of the region the resort of those who would for a time leave the tiring, nerve-straining experiences of our modern cities behind them and find quiet, rest, and health in the peaceful wilds of the Laurentian Peneplain of Canada.

THE DATE OF EMERGENCE OF THE CANADIAN SHIELD.

The earlier studies of Walcott (39) on the Cambrian, and the recent investigations of Ulrich and Schuchert on the later Paleozoic, faunas of North America have led to the conclusion that

> the present North American continent was in existence and practically in full development as land at the close of Algonkian time, and that since that period, the Canadian shield and other smaller Archean land areas have never been wholly submerged. The periodic encroachment of the sea on the Canadian shield attained considerable extent on the north and west and more particularly on the south. The east shore, on the contrary, remained nearly the same till comparatively recent time—probably Post-cretaceous. (37, p. 659.)

Accepting these conclusions, it would naturally follow that a land area exposed for so long a time as has since elapsed would have undergone extreme degradation, and we should naturally expect to find it exhibiting all the features characteristic of the penultimate stages of the geographic cycle.

On the other hand, if we investigate the features of the region under discussion, we are led to similar conclusions. The very even surface of the area, in almost every part from Labrador south around Hudson Bay to the Arctic Ocean, is found to truncate the structure of intensely metamorphosed igneous and sedimentary rocks, irrespective of their hardness or attitude. The metamorphism is such as to imply that they have been at one time buried deeply beneath the surface of an overlying land mass, and have been subjected to the strains and stresses of intense orogenic movements. The removal of overlying mass of rock must have occupied an immense interval of time. How great it is impossible to say. For part of the area at least, this degradation took place before late Paleozoic time, for we find Paleozoic sediments resting upon a modified peneplain surface. It seems probable that for the central portions the interval was much longer.[1]

In brief, a study of the physiographic features of the Laurentian Peneplain must undoubtedly lead to the conclusion that the Canadian shield has been, for an exceedingly long interval of time exposed to processes of erosion which were chiefly subaërial; and a study of the relations of the central peneplain surface to the surface upon which the Paleozoic sediments around the margin rest shows that at least parts of the peneplain were produced before later Paleozoic times. It is only by stratigraphic studies, however, that approximate dates can be assigned for the origin of specific features.

FEATURES OF THE PLANATION SURFACE.

1. *Character of the sky-line.*—The most dominant and striking feature of the whole region, from the northern part of the interior of Labrador following approximately the median line of the region around to the south of James Bay and northwest toward the Arctic Ocean, is the remarkably even character of the sky-line. With few exceptions, to be noted elsewhere, almost everywhere in the interior it is found that from any slight elevation, which lifts the observer above the tree line, the bounding horizon is very even and almost circular. The many traverses

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[1] It must be noted in this connection that Lawson, writing in 1888, dissents from the view that the Archæan rocks were ever elevated into mountains (18, p. 23).

which have been made across the different parts of the area show, particularly for the western portion of the peneplain between the Great Lakes and the Arctic Ocean, that for many miles the greatest elevation is often not over fifty feet higher than the adjacent lowest depression, and as a rule the actual surface may be described as gently undulating. Occasionally the measure of relief may equal one hundred feet, but, particularly in the western arm of the peneplain, elevations of this amount are prominent landmarks, visible for many miles, and from a distance are frequently seen to stand above the even sky-line of the adjacent regions, so that they may more properly be classed as monadnocks. In the country to the south of James Bay the measure of relief is somewhat greater, but the even sky-line, occasionally intercepted by residuals, is still the dominant topographic feature. In the eastern portion of the peneplain for long dis-

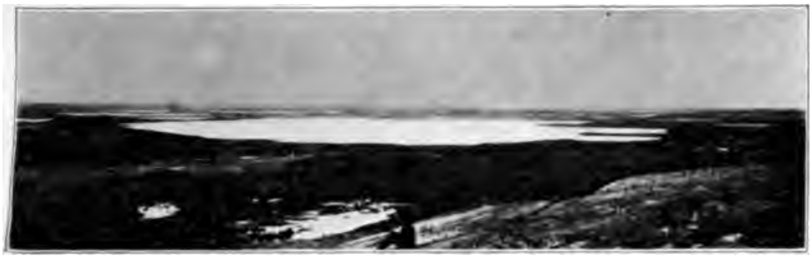

FIG. 2.—East coast of Hudson Bay, six miles up the Povungnituk River. Elevation 50', looking inland.

(*Photograph by A. P. Low, 1899.*)

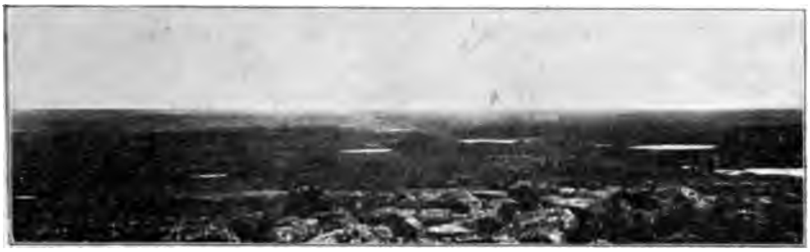

FIG. 3.—East side of Hudson Bay, thirty miles up Sorehead River. Elevation about 150', looking inland.

(*Photograph by A. P. Low, 1899.*)

tances in the central parts the surface is practically the same as on the western half. Toward the margins it is more rugged or uneven, while toward the extreme northeast, close to the Atlantic coast, there is a narrow range of mountains rising prominently above the peneplain surface.

When the character of the surface is considered more in detail, it is found that, except for some very small areas, and in places where the peneplain surface is buried beneath the much younger glacial and alluvial deposits, the surface is nowhere quite flat, but is covered with low, rounded domes and ridges, which are roughly parallel to themselves and whose longer axes conform in general to the strike of the rocks.

The remarkably even character of the sky-line together with the universal distribution of many large and small lakes at levels little below that of the even sky-line, justifies the assumption that differences of elevation between different water bodies in the depressions upon the surface of the plain represent closely the differences in elevation between portions of the peneplain adjacent to each of these water bodies respectively. On this basis it will be found that the average gradient varies in different parts from one to about four feet per mile. For example, between Selwyn Lake (1,340′) and Doobaunt Lake (500′), along the line of the Doobaunt River, west of Hudson Bay, the average gradient is 2.8 feet per mile for a distance of approximately 300 miles. A section eastward from Cree Lake (1,530′) to the junction of the Churchill and Little Churchill Rivers shows an average gradient of 1.8 feet per mile for 450 miles. A study of the profiles of the Canadian Pacific Railway between Montreal and Winnipeg, where the line runs over the upland, shows between Buda (1,472′) and Brulé (1,355′) a fall of 117 feet in a distance of 146 miles; between Cartier (1,398′) and Lac Poulin (1,504′) the rising gradient is 106 feet in a distance of 129 miles. In central Labrador a section between Lake Nichikun (1,760′) and Lake Kaniapiskau (1,850′), and thence to Lobstick Lake (1,630′) above the Grand Falls on the Hamilton River, shows an ascending gradient of 90 feet in the first 100 miles, and then a descent of 220 feet in 200 miles, or a mean gradient of approximately a foot per mile. In a direction along the divide (1,550′) from southeast of Lake Mistassinni to Lake Kaniapiskau (1,850′) the rising gradient is almost exactly one foot per mile.

By way of comparison, from the profiles of the Canadian Pacific Railway between Winnipeg (757′) and Calgary (3,428′) in the foothills of the Rockies, the gradient is found to be 3.18 feet per mile. Between Edmonton (2,407′) and East Selkirk (744′), along the old location line, *via* the Yellowhead Pass, the gradient is 2.1 feet per mile. In each of the above cases, if shorter sections are taken on each of the three prairie steps, it will be found that for each step the gradient across the plains is much less than the figures here given.[1]

The comparison of the two gradients across the great plains with the gradients upon the peneplain surface, taken in conjunction with the character of the sky-lines in the two areas, shows the appropriateness of the term "peneplain" as a term to describe the principal geographic feature of this topographic unit.

2. *Departures from the normal peneplain type.*—On an area reduced to a peneplain one would expect to find a gently undulating surface, with the larger streams meandering in broadly open valleys. Their power to erode would long before have begun gradually to diminish, in part by reason of the lessened rainfall due to the reduced elevation above sea-level, in part because of the reduced grade. Their sluggish character, diminished water-supply, and low velocity will not enable them to transport the waste of the land except in a very fine state of division, or in solution. Hence the surface of a normal peneplain would be composed of mantle rock of considerable depth, at the surface very fine in texture, and gradually changing with depth to unaltered bed rock. A very even surface, deep soils, and streams which have long before lost the adjustments of early maturity, the absence of lakes, and an elevation little above sea-level must be characteristic features of a land area which has been reduced

[1] In the profiles taken along the lines of river valleys it is to be noted that the distances are estimated in straight lines, not along the stream courses. It will be found that the average gradient of the stream course is much less.

to the peneplain condition by the processes of subaërial degradation.

We have already seen that the Laurentian peneplain exhibits to a most marked degree the even sky-line and low surface gradients. We find, however, that it is almost devoid of mantle rock *in situ*. That which occurs, with the exception of an exceedingly small amount, almost too small to notice, was brought to its present location by glacial or aqueous processes of transportation. The drainage over most parts of the area is not well established; rapids and waterfalls are the most characteristic features of all the streams. The entire surface of the country is dotted with lakes, which are practically numberless; in places their area approaches 25 per cent. of the whole. And finally, parts of the peneplain are not now in accordant position with respect to sea-level. Thus, although the complicated and contorted rocks of the region are everywhere truncated by a surface which presents a remarkably even sky-line, in almost every other respect the features of the region are different from those characteristic of a peneplain. Since the production of the peneplain surface which traverses the rocks of the region, the surface of the plain has undergone profound modification, leading to the production of the present features.

In the descriptions which follow, the general nature of these departures from the normal type of peneplain will be described more in detail, and at the end of the paper a brief reference will be made to the processes which may have brought about these modifications. In general it may be said that the present attitude of different parts of the plain with respect to sea-level is due to a differential uplift, which, in parts of the area at least, is still going on. The later dissection of the plain, the carving of deep, broad valleys or of narrow canyons, seems to be a function of this uplift, though many of the first class of depressions here mentioned may antedate the peneplain. The absence of mantle rock *in situ*, the occurrence of the numerous lake basins, and the inmaturity of the drainage systems are usually attributed to the erosive action of glacial ice.

3. *Detailed descriptions of characteristic portions of the plain.*—

In the present attitude of the peneplain the highest part is found in central Labrador, where, to the south of Lake Nichikun, it reaches an elevation of approximately 2,400 feet above sea-level. The plain slopes outward from central Labrador toward Hudson Bay and the Gulf of St. Lawrence, the margins of the plain proper, near the coasts, being at considerable elevations.

In his report on explorations in James Bay and in the country east of Hudson Bay, drained by the Big, Great Whale, and Clearwater Rivers, Low describes the interior of this part of the peneplain as a

> rough table-land having an elevation of about 700 feet above sea-level near its edge, and slowly rising inland to over 2,000 feet at its highest. The edge of this table-land leaves the coast to the north of Cape Jones, and runs in a S. S. E. direction, so that to the southward there is an interval varying from ten to thirty miles between it and the coast. In this portion the general level is not much over 100 feet above the sea, and the soil is of Post-Pliocene clays and sands, with alluvium. . . . . The land is rolling and broken by low rocky Archæan hills, which make up about one third of the entire area. (23, p. 16).

The same writer describes the area of country stretching from the Gulf of St. Lawrence northwestward to Hudson Bay as

> a low-lying plateau of Archæan rocks. The height of this plateau averages about 1,500 ft. above sea-level, and rising slowly from about 1,000 ft. near the edge to about 2,000 ft. in the interior. The surface of this plateau is by no means flat, being covered by the low rounded hills, which are roughly arranged in a series of ridges more or less parallel to themselves and the general strike of the rocks. These hills are the stubs of extensive and elevated mountain chains which, from exposure to subaërial denudation, for countless ages, and from having been subjected to glacial action of later geological times, have been ground down to their present unimposing state. In the interior the difference of level between these ridges and the valleys separating them is small, the hills seldom rising 100 ft. above the general level. As the coast is approached the difference is more marked, the long action of ancient rivers having deeply cut out the principal valleys below the surrounding country, thus causing a more marked contrast in level, and at the same time much finer scenery. (24, p. 14.)

Summing up the statement of a series of levels in different parts of the Labrador area Low writes:

> The interior of the peninsula is almost flat, so that in an area of 200,000 square miles, there is not a difference of general level of more than 300 or

400 feet, and the highest general level of the interior is under 2,500 feet. A belt of land somewhat higher than the general interior follows the St. Lawrence coast, a short distance inland. The northern half of the Atlantic coast rises in a chain of mountains considerably higher than any other portion of the peninsula. Along the northern and western coasts there is no evidence yet obtained to show the existence of a coastal ridge, but rather a probability that the general elevation increases towards the interior. (24 p., 23.)

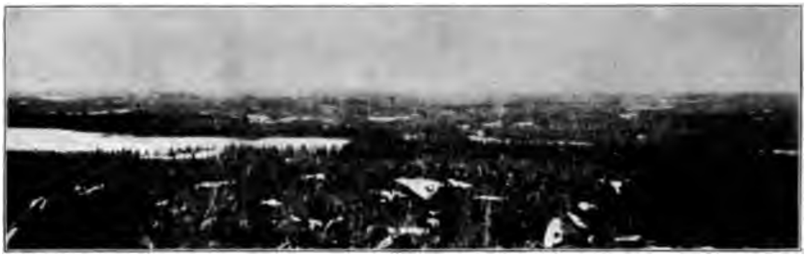

FIG. 4.—Interior of Labrador, country north of Lake Michikaman.
(*Photograph by A. P. Low, 1894.*)

The divide between Hudson Bay drainage and that flowing into the St. Lawrence lies almost midway between the two water bodies. Throughout the greater part of its course the divide is frequently not well defined; at times it is well marked. Low describes it in the vicinity of Lake Mistassinni as a ridge of hills forming an escarpment about 300 feet high. Elsewhere he mentions that this divide is a prominent topographic feature for over fifty miles.

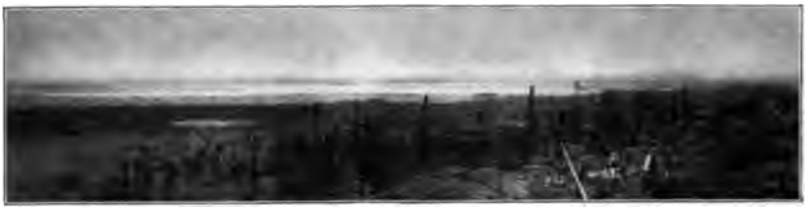

FIG. 5.—View of the country on the Hamilton River, about fifty miles above Grand Falls, showing the character of the interior plateau.
(*Photograph by A. P. Low, 1894.*)

The St. Lawrence portion of the Labrador division of the uplifted peneplain does not slope uniformly from the interior divide toward the gulf. On the contrary, there seems to be, as it were, a sag in the surface of the peneplain between these two locations. The margin of the plain parallel and close to the St. Lawrence River, in the vicinity of the outlet of the Saguenay River, reaches an elevation of over 1,500 feet, and there is a well-defined gentle swell, whose height approximates to this elevation extending from southwest of the Saguenay in the neighborhood of Quebec, for a considerable distance along the southeast margin of the plain to below the St. John River. Between this swell and the interior main divide is a gentle depression. The lowest part of this depression forms the well-defined basin of Lake St. John (314′), in this particular case probably located on a graben block. The majority of the streams rising near the interior divide are found to cross this marginal swell in the peneplain through deeply cut, steep sided gorges or canyons.

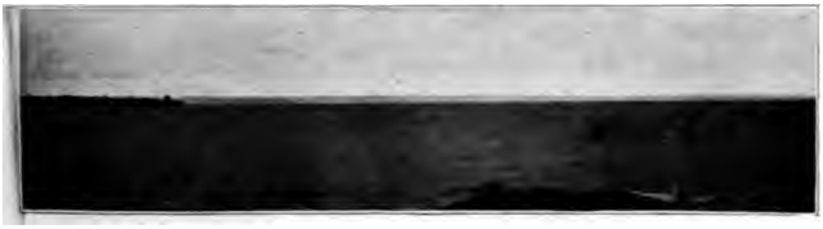

Fig. 6.—Looking across Lake St. John from the discharge of the Saguenay, the margin of the upland makes the even sky-line in the background.

(*Photograph by Dr. F. D. Adams, 1884.*)

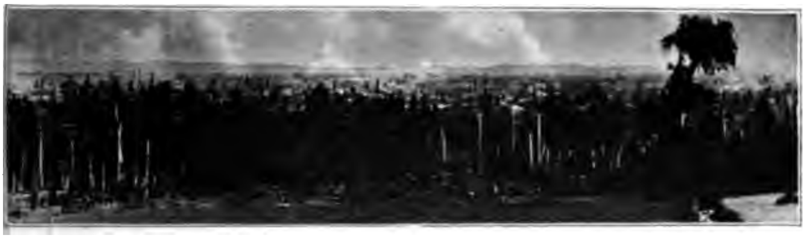

Fig. 7.—Central Ontario. The upland shows the less even sky-line of one of the pre-Paleozoic facets.

(*Photograph by Dr. A. E. Barlow, 1898.*)

(This photograph will accompany a detailed report on the geology of this area by Dr. F. D. Adams and Dr. A. E. Barlow.)

The best known, broadest, and deepest of these is the gorge of the Saguenay, a true fiord.

From the vicinity of Quebec westward to Lake Superior, and thence northward *via* Lake Winnipeg, Lake Athabasca, and Great Slave Lake, the convex margin of the peneplain is bordered by ancient sediments, Paleozoic for the most part; but in the extreme northwest Cretaceous deposits are found resting upon its surface. The inner or concave side of the peneplain to the south and west of James Bay, and extending as far north as Fort Churchill, is bounded by a narrow belt of Paleozoic sediments. North of Fort Churchill the ancient peneplain merges gradually with the modern coastal plain of Hudson Bay. The northern end of the western arm of the plain probably passes beneath Paleozoic sediments known to occur north of the Arctic circle. The surface of the peneplain north of the main divide and south of the lower waters of the Albany River and of James Bay, particularly that portion drained by the Moose River system, is almost completely buried beneath clays and sands, chiefly of glacial origin.

The divide on that part of the ancient peneplain south of James Bay lies nearly midway between the northern and southern boundaries of the plain, north of the city of Ottawa. From the vicinity of Lake Abitibi it runs westerly toward the most northern point of Lake Superior, so that in the longitude of Schreiber station, on the main line of the Canadian Pacific Railway, it lies not more than twenty-five miles north of the lake. From here it swings to the northwest, passing to the north of Lake Nipigon, and thence turns southwest toward Savanne on the Canadian Pacific, and continues southward, crossing the international boundary. A portion of the Archæan region lies to the south of the boundary in the states of Michigan and Minnesota, and portions of this area drain into Lake Superior. Following along the line of the western margin of the peneplain, however, from the international boundary as far north as Methy portage (lat. 56° 40′ N.; long. 109° 55′ W.) the main divide lies west of the peneplain and at the summit of the Rocky Mountain range. A subdivide, a little to the east of Lake Winnipeg, and on the peneplain, separates the headwaters of a few short, westerly flowing streams from the waters of streams flowing to Hudson Bay. All the waters from the river systems whose chief streams are the English, Red, Assiniboine, and Saskatchewan Rivers reach Lake Winnipeg (710′) just on the margin of the plain, and thence cross the plain in a broad shallow depression, *via* the Nelson River to Hudson Bay. North of the Nelson the Churchill River system also drains a considerable portion of the central plains across the ancient peneplain. Still farther north

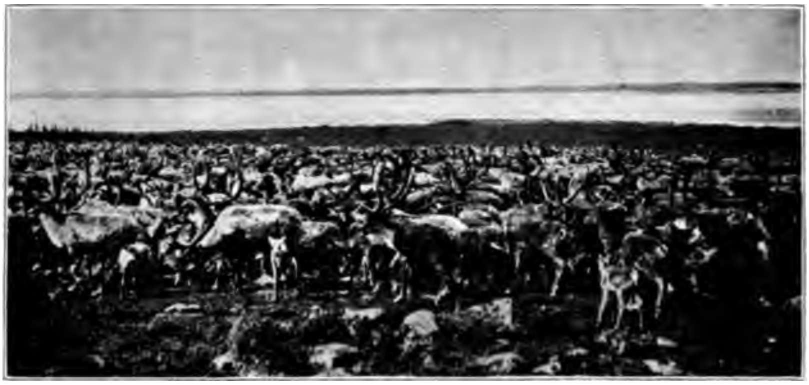

FIG. 8.—Caribou on the banks of the Doobaunt River, Keewatin District.
(*Photograph by J. B. Tyrrell, July 30, 1893.*)

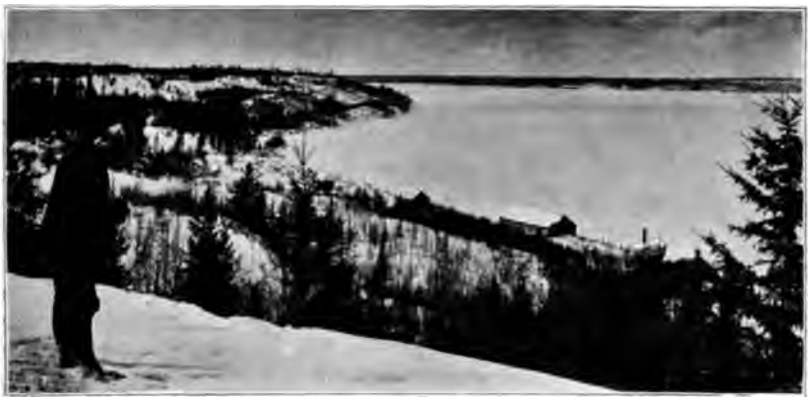

FIG. 9.—Great Slave Lake, looking north from Fort Smith.
(*Photograph by J. W. Tyrrell, 1900.*)

the main divide is again located on the peneplain, separating the Mackenzie River system from a number of river systems whose main direction of flow is a little to the east of north for nearly half their courses, and then eastward in broad, open valleys toward Hudson Bay.

It has already been noted that in central Labrador the main divide has a highest elevation of about 2,400 feet. South of James Bay the elevation of the main divide on the peneplain is about 1,400 feet above sea-level, as a maximum; in places it is somewhat lower. North of Schreiber it has an elevation of about 1,345 feet. East of Lake Winnipeg (710′) the sub-divide at the headwaters of the Berens River stands at about 1,400 feet above the sea. In the interior, north of the Churchill River, the elevation in places exceeds 1,600 feet. The divide north of Lake Athabasca stands at an elevation of about 1,400 feet.

Dr. A. E. Barlow, in his report on the Nipissing and Temiscaming map sheets, thus describes the topography of a portion of the central part of the peneplain to the south of James Bay:

> The general character of the country may perhaps be best described as that of an uneven or undulating rocky plateau, with a gentle slope toward the east and southeast. Although in detail the surface of this plateau is far from uniform, consisting of a succession of more or less parallel rocky ridges, with intervening valleys occupied by swamps or lakes, still the district as a whole has a general elevation varying from 900 to 1,200 feet above the sea. There are no very prominent hills, the highest seldom attaining a greater altitude than 300 feet above the surrounding region, while throughout most of the district, hills of 50 to 100 feet in height are rather conspicuous topographical features. The highest land in the whole area is situated near the northwest corner of the Temiscaming sheet, immediately to the west of Lady Evelyn (Mus-ka-na-ning) Lake, where a range of hills, of which Maple Mountain is the highest peak, rises to the height of a little over 2,000 feet above the sea, according to Dr. Bell.
>
> The influence exerted by the underlying rock on the general contour of the surface, is perhaps nowhere better exemplified than in the region embraced in this report. In the southern and southeastern portions, where the prevailing rocks are the various gneisses and granites included as Laurentian, there are no hills of any great height, the general surface presenting, as usual, a rather monotonous succession of low rounded hills, with corresponding shallow rocky valleys. In the northern and western portion, however, those areas in which the quartzites are present, as well as those in which the

plutonic rocks, chiefly granite and diabase, are prevalent, rise into rather important elevations; while those regions which are underlain by the slaty member of the Huronian, are on the other hand low and flat. A remarkable resemblance exists between the contour of the surface, occasioned by the presence of the diabase rocks, and that produced by the heavy-bedded and massive quartzite, that forms the highest member of the Huronian exposed in this district, both rising into comparatively high rounded or broken ridges and rendering the stretches of country where such rocks prevail, exceedingly rough and hilly. . . . . This rough and broken contour is in marked contrast to the flat surface characteristic of the region in which the slates obtain. (4 p. 21.)

McOuat also draws attention to the general level character of the country south of Lake Abitibi, and mentions the occurrence of two remarkable hills which rise more than 700 feet above the general level. Lawson in his report on the Rainy Lake country also draws attention to the generally even character of the surface, and mentions the striking contrast offered by several ridges which rise prominently above the generally even surface. (19, p. 11.)

Farther northwest, near Lake Winnipeg we find "The country near the river (Berens) . . . . is made up of many low hummocky, gneiss hills, which seldom rise twenty feet above the water, and are partly covered with a heavy clay soil" (Low, 21, p. 5). Nearer the sub-divide we find "The surrounding country is a vast, level swamp, broken only by a few knobs of gneiss, that rise from ten to fifty feet above the general surface" (21, p. 11).

Bell, describing the country along the upper Albany, also draws attention to the generally level character of the district (7, p. 18). J. B. Tyrrell's description of the physical features of the district along the line of the Doobaunt, Kazan, and Ferguson Rivers is as follows:

The general relief of the whole country is very low and unpronounced, much of it having the appearance of vast undulating plains underlain by sandy or stony till and covered with stunted spruce and larch or short grass and deciduous northern plants. Here and there rise rounded rocky hills, the highest of which in the neighborhood of Kasba Lake have altitudes of about 1,700 feet above sea-level. Northeast of Doobaunt Lake some prominent hills of green trap and red conglomerate form conspicuous features in the

> otherwise monotonous landscape. From Kasba and Daly lakes the country has a general and moderately regular slope northeastward until it reaches the highest raised beaches or post-glacial shore lines, after which the slope is more directly eastward toward the present shore of Hudson Bay. (34, p. 158.)

Elsewhere he writes:

> The northeastern part of this region is underlain by crumpled and distorted Archæan rocks, whose surface has, even in pre-Cambrian times, been reduced to an undulating plain, with very slightly accentuated contours. (35, p. 148.)

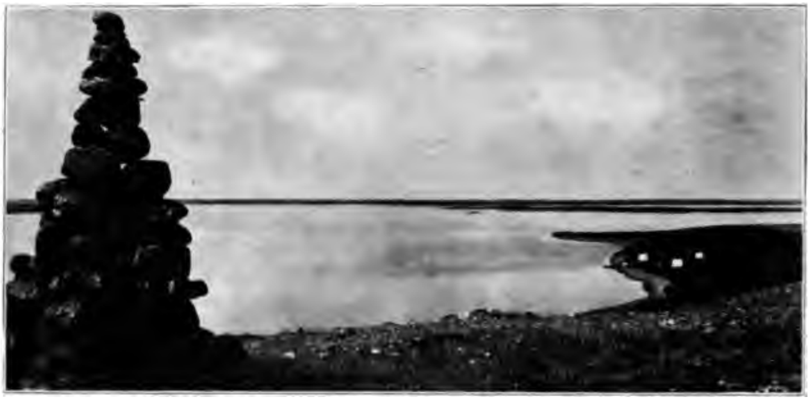

FIG. 10.—Sifton Lake and Cairn on Musk Ox Hill, District of Mackenzie. (*Photograph by J. W. Tyrrell, 1900.*)

Again, in a note on the Pleistocene of the Northwest Territories of Canada, Tyrrell writes:

> In general physical features the "Barren Lands" often closely resemble the great plains west of Manitoba along the line of the Canadian Pacific Railway, being undulating grass-covered country, underlain by till more or less thickly studded with boulders; but a hard granite knoll projecting here and there serves to remind one that the till is not here resting on soft Cretaceous shales and sandstones and at once accounts for the much greater abundance of boulders. In some places the surface is composed entirely of large subangular boulders, without any matrix of sand or clay, while the shores of Chesterfield Inlet, and part of the northwest coast of Hudson Bay, are bold and rocky. (33, p. 395.)

4. *Drainage features.*—A feature characteristic of the present drainage of the peneplain everywhere from Labrador to northern Keewatin and Mackenzie is that the upper courses of all the riv-

ers upon the plain consist of a series of chains of large and small shallow lakes occupying basins which are generally rock-bound, less often drift-blocked, and which spill over their lowest edge in a more or less ill-defined, sometimes braided stream, characterized by a succession of rapids or falls, to the next lowest basin. The lower courses of the streams flowing across the Hudson Bay coastal plain are generally well defined, the streams lying in valleys incised beneath the surface level of the coastal plain and drift deposits.

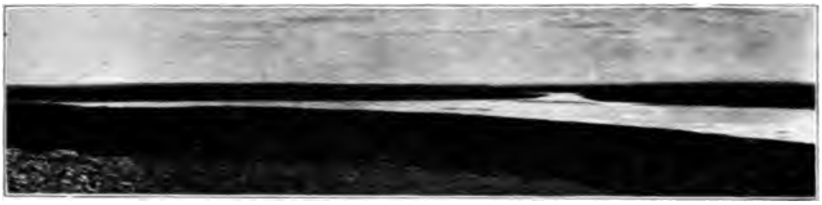

FIG. 11.—Junction of the Thelon and Hanbury Rivers, District of Mackenzie. (*Photograph by J. W. Tyrrell, 1900.*)

In the Labrador area the main streams in their upper courses upon the surface of the plain belong to the general type of streams upon the upland. When they approach the margin of the plain, however, they are found to occupy well-defined, often gorge-like valleys incised in the Archæan rocks of the plateau, often to a considerable depth beneath its surface. As a consequence of this, it is found that the lower courses of almost all the streams entering Hudson Bay on the east are characterized by a long series of falls and rapids, and are impassable by canoes, thus necessitating long portages when it is desired to

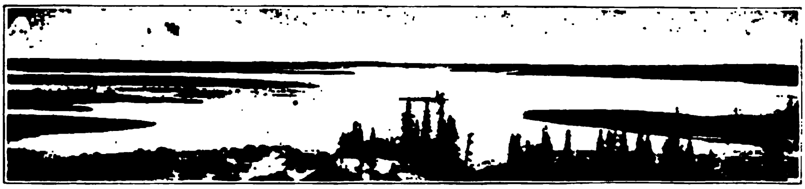

FIG. 12.—View on the Upper Thelon River from Cairn Hill, District of Mackenzie. (*Photograph by J. W. Tyrrell, 1900.*)

reach the interior. This is equally true of most of the streams flowing outward from the interior of the plateau to the Gulf of St. Lawrence, to the Atlantic, and to Hudson Bay. The streams that flow southeast into the St. Lawrence River and Gulf all cross the St. Lawrence swell, before described, in deep gorges incised to a depth of several hundred, and in places more than one thousand, feet below the level of the plain.

Low states:

> The rivers entering James' Bay from the east for their entire length, pass, so far as known, through Archæan country, and consequently present physical characters somewhat different from those on the west side. On their headwaters they flow on the general level of the country and are nothing but a succession of lakes connected by short stretches of rapid rivers. After they have attained considerable volume and as they approach the margin of the interior table-land they begin to assume a true river character; they flow with a moderate current, broken by short falls and heavy rapids, in old river valleys cut below the general level. Near the margin of the table-land the valleys become deeper, and the rivers are almost a constant succession of heavy rapids and falls until they reach the lower country, where they flow with a moderate current, with but few small rapids, in a distinct river valley between clay and sand banks of Post-Pliocene age. (23, p. 20.)

On the Stillwater River he notes that the country does not slope with the river, and consequently the bottom of the valley for several miles above Natuakami Lake is about seven hundred feet below the general level of the surrounding region. Referring to the Kaniapiskau, one of the streams flowing from central Labrador northward to Ungava Bay, he states:

> For sixty miles below the lake [Kaniapiskau] the river, like all the streams of the central area, flows nearly on a level with the general surface, or rather fills all the depressions along its course, and in consequence is made up of a succession of lake expansions connected by short stretches of rapids, where the river is often broken into several channels by large islands. Below this distance the channel contracts and in five miles the river descends more than two hundred feet into a distinct valley well below the level of the surrounding country; and from there to its mouth always follows a distinct ancient valley cut down into the solid rock from 300 to 1,000 feet below the surrounding country. Between the first and the second gorge, which is about eighty miles lower down stream, the river is almost a continuous succession of heavy shallow rapids so bad that the stream is not used by the Indians. At the second gorge or Eaton Cañon, the river passes through a narrow cleft in the

rocks and falls more than three hundred feet in less than a mile. Below Eaton Cañon the river continues with a very rapid current for one hundred and seventy-five miles to where it joins the Larch River, a very large branch from the westward. (24, p. 210.)

One of the best examples of this type of river valley is that of the Hamilton River. Low's description is as follows:

> The Hamilton River like the Koksoak and all the other large rivers of Labrador flows in a distinct valley cut down far below the general level of the surrounding country. If Hamilton Inlet, which is only a portion of the ancient valley now sunk below sea level, is included, the main valley extends inland nearly four hundred miles, and its present bottom is from six hundred to twelve hundred feet below the surface of the surrounding table-land. The upper portion of the river flows nearly on a level with the lower portions of the central tableland, and like the Kanapiskau spreads out into lakes or in other places is broken into several channels by large islands, so that it is often difficult to define or follow the principal channel. Near the Grand Falls the river changes from a meandering stream that follows the lower levels of the general surface, and contracting into one channel is precipitated into the ancient deeply cut valley. In twelve miles this great river, with a volume nearly equal to that of the Ottawa where it flows past the Capital, falls seven hundred and sixty feet from where it issues from a narrow cañon into the wider valley. The first part of the descent is seven miles of rapids with a total fall of two hundred feet. The river then contracts into a narrow inclined, rocky trough down which it rushes with a tremendous velocity and is spurted out in a solid mass over a steep precipice into a circular basin three hundred feet below. The basin into which the river falls is about two hundred yards wide and is nearly surrounded with vertical rocky cliffs, that rise five hundred feet above the water . . . . From the basin the river rushes out through a narrow cañon cut vertically into the rock at right angles to the falls. This cañon on the level of the surrounding table-land is from one hundred to three hundred feet wide, but at its bottom is often less than fifty feet across. Down this narrow zigzag gorge the river rushes in a continuous rapid with a fall of two hundred and sixty feet from the basin to where it issues into the wider ancient valley eight miles away. (27, p. 212.)

In the report on the southern portion of Portneuf, Quebec, and Montmorency counties, Quebec, Low notes that

> The rivers falling from the high interior plateau are much broken by rapids and falls, and owing to their rapid descent are liable to great and sudden variations in volume of discharge . . . . The valleys of the rivers and their tributary streams are deep, with almost perpendicular walls, rendering cross country travel very arduous, and in places impossible, while the dense forest growth adds to the difficulties and hides many of the rock exposures. (25, p. 7.)

The valley of the Betsiamites, described by Low (20, p. 7), and the well-known gorge of the Saguenay are two of the most striking of these deep valleys which traverse the St. Lawrence swell.

The drainage of the central portion of the peneplain south of James Bay presents somewhat similar features. Barlow draws attention to the fact that

> Probably one of the most interesting of the physical features presented by the district is the valley occupied by Lake Temiscaming and the Ottawa River. The greater portion of this valley is a very steep rocky gorge, fringed on either side by lofty hills or perpendicular cliffs which rise abruptly to a height of from four hundred to six hundred feet above the surface of the water, while the average of a large number of soundings indicate that the lake has a mean depth of over four hundred feet. The depression, therefore, occupied by these waters would be about one thousand feet below the level of the surrounding country, and as the bottom of the lake, wherever examined, consisted in the deeper portions of a very fine gray unctuous clay or silt, this depth may have been much greater before the accumulation of this material. From Mattawa to the mouth of the Montreal River these abrupt and rocky shore-lines prevail, but above the mouth of this stream the lake undergoes considerable expansion and the shores exhibit a more gradual slope towards the surface of the water. The traveler ascending the Ottawa River is thus usually impressed with the mountainous character of the district, but an ascent of the hills on either side at once shows that the adjoining country is comparatively level, and that what appeared as a range of hills are in reality the inclosing walls of this great valley. (4, p. 23.)

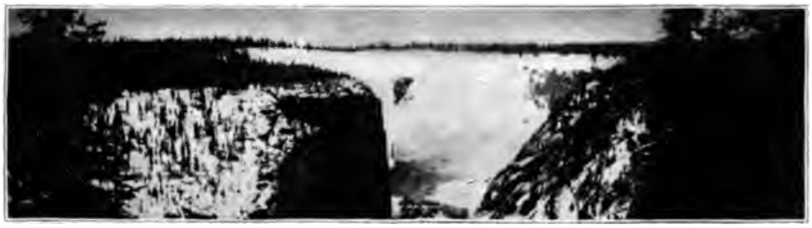

FIG. 13.— Post-glacial gorge of the Hamilton River, immediately below the Grand Falls. The vertical cliff on the left has a height of 500.'

(Photograph by A. P. Low, 1894.)

He also states that "the Mattawa and Montreal Rivers, in a lesser degree the Sturgeon and Temagami Rivers, occupy rather deep and important depressions in this rocky plateau."

On the western arm of the peneplain the upland still presents the same general features. The head-waters of all the rivers flowing to James Bay, where they flow over Archæan rocks, alternate between long lake-like expansions with little current, and short, contracted portions characterized by rapids and falls. Where they cross the ancient or modern coastal plains the fall is uniform, and usually, except at times of high water, they present an almost unbroken succession of small shallow rapids full of bowlders and gravel bars. (See Low, 23, p. 18.)

Tyrrell draws attention to the fact that

> A particularly noticeable feature of the "Barren Lands" is the absence of valleys for the rivers. The Telzoa River probably the largest stream in all that country, is, through the greater part of its course from Daly Lake to the head of Chesterfield Inlet, merely a succession of lakes of larger or smaller size lying in original depressions in the till or rock, connected by stretches of rapid water flowing in one or more shallow, tortuous and often ill-defined channels frequently chocked with boulders. (33, p. 395.)

The deep, steep-sided gorges cut below the level of the plain are less in evidence on its western part. Shallower gorges occur, but generally only for short stretches along the rivers. There are, however, a number of broadly open valleys, more or less occupied by sediments, which have been provisionally classed as Cambrian. Tyrrell states

> It would seem probable that the drainage has always followed the main valleys which still trench the surface, running more or less at right angles to the mountains. The pre-Cambrian valley of Chesterfield Inlet, extending eastward towards Hudson Strait, and westward towards Great Slave Lake, and the post-Cretaceous valley of the Saskatchewan, extending towards the lower valley of the lower Nelson River, and many other valleys running more or less parallel to these, go to prove the general correctness of this statement. (35, p. 149.)

The partial re-excavation of some of these depressions, occupied at least in part, by early Paleozoic sediments has given rise to the eastern extension of the basins of Lake Athabasca, Great Slave Lake, and Great Bear Lake. Reference has already been made to the valley of Chesterfield Inlet, and it is not improbable that Wager River (or Inlet) north of this owes its origin to a similar cause.

Valleys similar to these, containing sedimentary rocks, are also known to occur in the Labrador area. Low has reported the finding of sediments, provisionally classed as Cambrian, in the valleys of the Kaniapiskau and the Upper Hamilton Rivers. A somewhat similar series of sediments, the Manitounuck Series of Bell, occur along the east coast of Hudson Bay—lying below the level of the edge of the interior plateau, dipping seaward at low angles, presenting a well-defined cuesta front toward the plateau. In places the foot of the cuesta is submerged, but the unsubmerged portions form a series of coastal islands.

A series of sediments, for the most part classed as Cambrian, also occur in the Mistassinni basin. Ordovician outliers are found in the Lake St. John basin; Ordovician and Silurian strata occur in the northern part of the deep valley before noted as being occupied by Lake Temiscaming. Ordovician strata are also found in the Lake Nipissing basin. North of Lake Superior, particularly to the south and west of Lake Nipigon, is a well-developed series of non-fossiliferous ferruginous sandstones and dolomites resting upon the peneplain, and showing typical cuesta form. Subsequent to the development of the cuesta form on these sedimentary outliers they seem to have been overflowed with diabase sheets, and in some cases the earlier land form has been preserved beneath the more recent flow.

5. *Topographic depressions.*—A comparative study of the various depressions which go to make up the relief of the peneplain surface, as it is today, suggest a provisional recognition of three distinct types.

a) The broad, shallow depressions between the more or less hummocky or undulating ridges which occur upon the upland itself, and which are probably in the main of contemporaneous origin with the surface of the peneplain, and are presumably due to local differential erosion, and subsequent denudation.

b) Broad, open depressions, which are generally in part occupied by sediments provisionally classed as Cambrian.

c) Deep, narrow channels, in places gorges, with steep, often inaccessible sides, distinctly incised beneath the level of the adjacent upland. (These are of two types, short and relatively shallow, and long and generally deep.)

Bay, and part of the waters flow *via* the Cochrane River and Wollaston Lake to Lake Athabasca, and eventually reach the Arctic Ocean. Similar lakes, both large and small, with outlets in two directions, are quite frequently found manywhere upon the peneplain.

b) *Depressions containing sedimentary deposits.*—The occurrence of valleys occupied by sediments which have been assigned to the Cambrian has been reported by Low in Labrador and by Tyrrell in northern Keewatin and eastern Mackenzie. Reference has already been made to some of these in a previous section; the occurrence of Paleozoic sediments in the basins of Lakes Nipissing, Temiscaming, St. John, and Mistassinni has also been noted.

Low in describing these valleys in Labrador mentions that the streams are often from 500 to 1,000 feet below the level of the plateau. The heads of the valleys are from 100 to 300 miles from their mouths, and at the upper ends the rivers descend from the level of the interior in a succession of heavy falls through narrow gorges, where processes of erosion are at present slowly extending and deepening the valleys. The valley of the Hamilton River he describes as being from 700 to 1,200 feet below the level of the plateau. In some cases these ancient valleys have been more or less filled with glacial débris, and the modern streams for parts or all of their lengths have taken new courses.

Some of the depressions in which these sediments occur seem to be ancient, broadly open valleys, and are considered by those who have had the opportunity of studying the region in the field as of pre-Cambrian age—In the case of Chesterfield Inlet, Tyrrell notes that the sides are deep and in places cliffed. Back's description of the country immediately north of the east end of Great Slave Lake would lead one to infer that the sides of this valley were also well defined.[1]

In the Labrador regions the margins of the depressions in which the pre-Cambrian sediments (so-called) occur are well defined. This is strikingly true of the lower and partly submerged valley of the Hamilton River. The Mistassinni depression is bounded by a well-marked scarp on the southeast, and a less definite, but still distinct, margin on the northwest.

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[1] See also Fig. 9.

The Lake St. John basin seems to be of a distinctly graben type; its margin is well defined, often cliffed or scarped; and all the streams tributary to the lake spill over the edge of the basin from the adjacent upland each in a series of waterfalls and cascades, often visible many miles away from the open lake.

The sediments in Lake Temiscaming and Lake Nipissing basins are in valleys lying below the level of the plain. The sediments in the vicinity of Lake Nipigon rest directly upon the plain, and rise above its surface.

In the greater number of cases it seems that there is a well-defined margin to the valley. In the case of some of those in the localities referred to above it may be possible that they antedate the peneplanation epoch, and that the sediments lying within them have been partly re-excavated since then. In the case of Lake Nipissing and Lake Temiscaming depressions, and possibly in the case of Lake St. John and Lake Mistassinni, the depressions may also be of a date antecedent to the peneplanation.

Barlow notes with regard to the Lake Temiscaming depression, and of others in that vicinity, that they bear no significant relation to the direction of the movement of the glacial ice, in fact, they lie at various angles up to as much as ninety degrees to the general direction of the movement ot the ice-sheet. He also notes that many of them cut across hard and soft rocks alike, and are independent of the strike of the structure of the rocks.

The character of the bounding walls, and the preservation of Paleozoic sediments in the bottoms of many of these valleys, would suggest that they are graben formed after the deposition of the sediments, and that the sediments are preserved in them because they were below the base level of erosion at the time when the balance of the similar sediments on what are now the adjacent uplands were removed. The fact that in many cases streams cascade down the sides of these valleys in ungraded channels suggests that this faulting has been quite recent. It is doubtless possible that in some cases where these valleys open out on the coast, that hanging lateral valleys may be due to the deepening and widening of the main valley by an ice-stream; but many of the type of depressions here referred to not only lie in regions which can never have been at the edge of the ice-sheets when they were in motion (or at least at their points of discharge), but seem to be completely inclosed by the bounding scarps except for the narrow outlet through which the present drainage passes.

In the majority of cases there is not sufficient available evidence to warrant an extended discussion of this very interesting problem.

c) *Gorge and canyon valleys.*— Narrow, steep-sided valleys and gorges, sometimes many miles in length, sometimes only extending for short distances, are of frequent occurrence in various parts of the peneplain. Reference has already been made to a number of them which are known to occur in the Labrador area, through which the drainage of the interior upland passes down to Hudson Bay, to the River St. Lawrence or to the Atlantic Ocean. One of the most interesting of these is the gorge of the Hamilton River, described by Low[1] as occurring above the more broadly open, partly submerged pre-Cambrian valley (so-called) of the lower part of the same river. The numerous rivers which enter the Gulf and River St. Lawrence from the northwest in every case pass through deep, steep-sided valleys, often canyons with unscalable walls, at times cut to a depth of over one thousand feet below the level of the peneplain. The valley of Moisie has been described by Hinde, the Bersimis by Low, the Saguenay the best-known of all, by Laflamme and Dumais.

Farther west the depression occupied by the lower part of Lake Temiscaming and the Ottawa River as far down as Mattawa seems to belong to this category. In the immediate vicinity of Lake Temiscaming there are a number of other gorges and valleys, the former much narrower and smaller than the Temiscaming depression, cut beneath the surface of the plain, at times even across weak and hard rocks alike, independent of the structure.

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[1] See above p. 641.

The edge of the plain along the north shores of Lake Huron and Lake Superior stands at a considerable elevation above these water bodies, and there are many south-flowing streams in this locality occupying steep-sided valleys incised well beneath the peneplain. In the northwest part of the area similar gorge-like valleys occur, but they are generally smaller, shorter, and are less prominent features.

So far as known, the valleys of this class are never found to be occupied by pre-Cambrian sediments and always have a well-defined "shoulder,"[1] where the gradient curve of the valley side intersects the flatter curve of the upland surface, and in their general relations suggest that they date their origin from a time subsequent to the period of planation.

6. *Monadnocks.*—In the various descriptions which have been quoted above it will be noted that frequent reference is made to the occurrence of residual domes and ridges which stand prominently above the generally even surface of the peneplain. In northwestern Labrador there is a narrow range of mountains described in part by Bell (5) and by Daly (9), reaching in places an elevation of about six thousand feet above sea-level. The range is narrow, having only a width of about fifty miles. The somewhat meager descriptions would lead one to infer that this range, like that of the less rugged Adirondacks in New York state, represents residual mountain peaks which have not been reduced to the peneplain condition. With the exception of these two small and widely separated areas, the residual elevations rising above the peneplained surface are generally more or less isolated domes and ridges, and they are found in all parts of the region. Their elevation and development seem to depend largely on the character of the material of which they are composed, and of the material by which they are surrounded. The most prominent monadnocks known within the area seem to be those mentioned by Barlow and McOuat as occurring in the region west and north of Lake Temiscaming, where hard quartzite ridges stand in places as much as seven hundred feet above the plain. The Baraboo ridge in Wisconsin,

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[1] See 41, p. 155.

an outlying monadnock ridge rising through the Paleozoic sediments, is comparable with these, and it is not impossible that its height above the peneplain on which it stands, but whose surface in this vicinity is obscured by the sediments, may be even greater.

Another excellent example, and one of considerable historic interest in connection with Logan's early work on the geology of the Archæan, is Trembling Mountain, lying north of the Ottawa River, and to the northwest of the city of Montreal, The mountain is a domed monadnock rising over 800 feet above the general level of the plateau, and about 2,380 feet above sea-level.

7. *Lakes.*—Reference has already been made to the fact, characteristic of the whole area, that the majority of the minor depressions on the surface of the peneplain form innumerable rock-basins in which the water gathers to form large and small island-dotted lakes. In addition to lakes of this class, which are usually very shallow and with very intricate shore lines, we occasionally find several other types.

One of the commonest of these is longitudinal lakes occupying old valleys which are more or less blocked by débris or by other geologic causes, in some cases presumably differential uplift. There are other examples of long, narrow lakes whose depressions are ascribed to the erosion of softer dikes. Over fifty years ago Agassiz drew attention to the fact that many of the bays and points on the shores of Lake Superior owed their origin to the erosion of soft dike rocks. More recently Bell has explained the origin of certain channels along the Lake Huron shore, and the longitudinal basins of certain inland lakes north of Lakes Huron and Superior, by a similar process.

The most interesting of the lakes of the longitudinal type is that of Temiscaming and the "Deep River" of the Ottawa adjacent to it. Dr. Barlow's description of this lake has already been mentioned, and his description of the character of the depression which it occupies has been quoted above. Whether the depression is of the graben type, somewhat similar to Lake Tanganyika in central Africa, or whether it is to be ascribed to the blocking or warping of a preglacial gorge is at present impossible to say. The character of the walls and the occurence of silurian sediments within the basin certainly suggest that it is of the graben type.

THE PENEPLAIN FACETS.

The relations of the Paleozoic sediments around the southern border of the plain to the peneplain surface suggest several interesting problems. In a former paper (41) the writer drew attention to the fact that there seem to be some grounds for surmising the existence of at least two peneplains cut upon the Archæan rocks and meeting at a very low angle. The data on which this suggestion was based are in part repeated here, with the addition of a few facts since obtained which bear on the same subject.

In the earlier part of this paper attention was drawn to the remarkably even sky-line exhibited by the plain everywhere in the interior, and it was mentioned that the average gradient in the interior rarely exceeded four feet per mile. In the central part of the province of Ontario it is found that radially from the upland surface in the vicinity of Haliburton Lake (the highest point in this part of central Ontario) to a number of points along the base of the Ordovician escarpment between Georgian Bay and Kingston, the average gradient over the surface of the peneplain is nearly nine feet per mile. At Toronto a well boring has shown that the crystallines are about eleven hundred feet beneath the present surface. Two other borings — one at Cobourg and the other in the township of South Fredericksburg — indicate that the floor is over five hundred and over six hundred feet respectively below the surface at these localities. The average gradient beneath the sedimentary cover along a series of lines from the foot of the Ordovician escarpment to the bottoms of these borings indicates that the gradient beneath the cover varies from twenty-two feet per mile in the western portion of the district to over forty-one feet per mile at the eastern end. The relative attitudes of these two surfaces are represented in Fig. 14, where *AB* represents the edge of a cross-section of the plain beneath, and *BC* the edge of a cross-section of that outside the sedimentary area. Such a comparison is quite justifiable because the numerous outliers north of the edge of the escarpment indicate that the surface over which the average gradients on the Archæan have been taken has been at one time buried beneath the sediments, and this surface has a remarkably even sky-line.

In the province of Manitoba, at Deloraine, a well has been driven to a depth of 1,943 feet below the surface and 108 feet into the Dakota sandstone. The bottom of the well lies about 299 feet below sea-level and 1,009 feet below the surface of Lake Winnipeg. The Archæan surface beneath the sediments, making no allowance whatever for Silurian and Ordovician sediments which probably underlie this sandstone, must thus have a gradient of about six feet per mile, and probably it is actually more than double this amount. East of Lake Winnipeg the gradient upon the Archæan to the summit of the subdivide, along the same line, is less than two feet per mile.

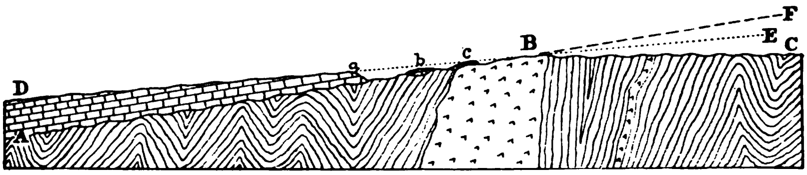

FIG. 14.

The relative positions of these two plains (reference to a possible third plain upon the surface of the Paleozoic sediments is here omitted) suggest certain problems, which may be summarized thus:

1. Do these two plains represent two distinct periods of planation?

2. Are *AB* and *BC* of the same age, but now discordant by warping?

3. Did the former plain *AB* once extend upward in the direction of *BF?*

4. Is the discordance between *AB* and *BC* produced by warping?

It should be added that the data at present in hand are not enough to determine whether *AB* and *BC* represent two intersecting plains, or are portions of a continuous curve. It may also be noted that the data given above, taken in conjunction with the progressive overlap of higher and higher geologic horizons upon the peneplained surface, as one proceeds toward the northwest, suggest that there are even more than two peneplains. Each plain may be regarded as a facet cut upon the Canadian shield. During the long interval of Paleozoic time a succession of these facets intersecting at very low angles would be formed as the land slowly sank and the successive formations were laid down. The great central part of the area upon whose surface the remarkably low gradients have been observed would represent the youngest of the facets, the region upon which the planation processes had acted longest. The partial removal of the Paleozoic covering has already exposed several of the older facets.

Similar relations to those noted above as occurring in Ontario between two plains of degradation upon the crystalline rocks have been found by Van Hise in Wisconsin (38), and by Smyth in the region south of Lake Superior (31). Darton has described a somewhat similar case in Virginia (10). In the Grand Canyon of the Colorado we have an actual transverse section of two such intersecting plains, both older than the Cambrian, but meeting at a much higher angle than that noted for the two plains near the margin of the Canadian shield.

SUMMARY.

From a physiographic standpoint the Canadian shield can be described as an ancient peneplain which has undergone differential elevation; has been denuded, and subsequently slightly incised around the uplifted margin. At several places on the margin, as exposed today, the dissection may be regarded as submature. Around the southern margin between Montreal and Winnipeg there are traces of a peneplain (or probably more than one) of still earlier date, upon which Paleozoic sediments were laid down, and which has been uncovered by processes of degradation and denudation since the differential uplift of the latest peneplain. The region is now in an extremely youthful stage of a new geographic cycle. It is bordered on the west and south by a belted ancient coastal plain whose mature drainage adjustments have been subsequently modified by glacial action, and in part by differential uplift. On the southeast the normal development of the ancient coastal plain has been in part retarded and modified by orogenic movement and dynamic process. Traces of the normal coastal plain development are, however, in evidence in a number of localities between Montreal and Anticosti.

The inner concave margin of the plain is marked by a depression occupied by the waters of Hudson Bay. To the south and southwest of the southern part of the bay there are traces of an ancient belted coastal plain with a convex south-facing cuesta development. For the most part this ancient coastal plain is buried beneath glacial débris and the sediments of the young coastal plain, the latter being superposed upon the former. This young coastal plain borders Hudson Bay on all sides, and the consequent drainage from the interior has incised well-defined valleys in the soft glacial and marine deposits, the interstream areas being little dissected. This modern coastal plain is of varying width up to a maximum of nearly one hundred and fifty miles.

The denuded peneplain surface, although destitute of mantle rock *in situ*, is strewn with glacial débris often of considerable amount. In the interior of Labrador this material is often very coarse, consisting of huge blocks and bowlders, with, however, considerable amounts of finer débris. In the parts to the south of James Bay, particularly in the Moose River basin and as far south as the height of land, the plain is almost completely buried beneath unmodified and modified glacial drift. Glacial drift in less amount, often fine-textured, at times coarse rock débris, occurs over the whole of the western portion of the peneplain. There are, however, areas of considerable extent where the amount of drift is very limited.

In the Labrador region there is a limited forest growth in the hollows. Most of the interior is bare and barren. In Quebec and in Ontario south of James Bay the region is densely forested.

The forests extend over the western portion of the plain to a short distance north of Great Slave Lake. Beyond this the region is treeless, moss-covered tundra. South of the forest line there are frequently large areas floored with glacial drift and forming numerous muskegs (or swamps) above whose surfaces the crystalline ridges and glacial kames and eskers project.

SOME PROBLEMS OF GENERAL INTEREST.

Aside from the strictly geologic problem of the origin and relations of the rock complex of which the Canadian shield is composed, there are a number of secondary problems of interest alike to the geologist and to the physiographer. Although it is not proposed to enter into an elaborate discussion of any of these problems at present, the time seems not inopportune to outline a few of those which are of general interest, and which are closely associated with one another.

1. *The former extent of the Paleozoic cover.*—The first of these which suggests itself is one to which reference has often been made. Did the Paleozoic sediments ever extend across the interior divide? Opinion seems somewhat divided on the answer to be given to this question. No doubt additional light will be thrown upon it when the fauna of the Paleozoic sediments occurring to the south of Hudson Bay can be adequately studied. The occurrence of the inlying areas of Paleozoic deposits, already referred to as occurring in the several depressions between Lake Mistassinni and Lake Nipigon, is generally regarded as strong evidence of the extension of these sediments at least across that portion of the plain which lies to the south of Hudson Bay.

To the physiographer the problem has an added interest from the fact that, if these sediments once extended completely across the peneplain, the questions arise: Is the present surface of that plain approximately the one upon which they rested; or has the surface upon which they were deposited been removed long since? Would it be represented by the extension of the peneplain of earlier date (which, it has seen shown above, probably exists) toward the locus of the present main divide?

The answer to these queries seems to be intimately associated with the second problem which suggests itself: What is the origin of the peneplain surface as to the time and process? At present it is quite certain that the evidence available is inadequate to solve the problem.

2. *The subaërial origin of the peneplain and the date of origin of the principal plain.*—As already noted, the stratigraphic studies of Walcott, Schuchert, Ulrich, and others have shown that at the beginning of Ordovician time the greater portion of the Canadian shield was above sea-level, and that since early Cambrian time it has never been wholly submerged. The work of Laflamme, Adams, Lawson, and others has shown that along the southern margin of the peneplain from Lake St. John to Lake Winnipeg, where the plain passes beneath the Ordovician sediments, it possesses the same hummocky character and fresh rock surface as it does in districts remote from the margin. Between the farthest outliers (exclusive of the outlying areas which may owe their preservation to the downthrow of fault blocks) there is a belt of the uncovered presedimentary surface, which shows all the features everywhere characteristic of the modified peneplain. Hence not only must the portion of the plain adjacent to the areas now overlaid by Paleozoic sediments be of pre-Ordovician date, but the dissection which it has undergone must also be pre-Ordovician. The dissection is regarded as of different date from the planation, because the gradient curves of the valley sides are not accordant with the flatter curves of the surface of the plain, often meeting the latter at an angle. The valleys are regarded as younger than the plain, because in no single instance do they contain sediments that have been derived from the adjacent plain. Along the margin of the plain their filling is always of the same materials as that with which the plain itself is covered—usually Ordovician limestone. The forms of the valleys and their relations to the plain are such that they would not be attributed to marine erosion.

During the transgression of the Ordovician sea it is conceivable that the earlier surface of subaërial origin may have been replaced by one of marine planation, assuming a time interval long enough. It is now generally admitted that during a time interval of sufficient duration to permit of the foundation of a plain of marine planation of any considerable breadth, the land of a very much larger area would be reduced almost to base-level by subaërial processes. If so, temporarily assuming that the margin of the peneplain, from which the Paleozoic sediments are known to have been removed, owes its plain character to marine planation, it would follow that the interior portions were principally of subaërial origin. If the marginal portion of the plain owed its plain character to marine erosion, we should expect to find the débris removed from the ridges deposited in the hollows, since the waves and currents tend always to produce an evenly graded floor. In the field no trace of this can be found. The Ordovician limestones often rest directly upon the plain surface and pass down into the adjacent hollows where the sides are not very steep. Where they are steep the lower beds abut against the valley walls and are conformably overlaid by beds which rest upon the plain. Nowhere has any accumulation which can be regarded as distinctively a product of marine planation been reported. Fossils (corals, crinoids, orthoceratites) are found in the lower limestone beds sometimes within a few inches of the Archæan rock, in some few cases actually attached to it. From the fact that these are not comminuted it may be inferred that the conditions of transgression, at least in the localities where they occur were such that the waters were moderately quiet; and from the absence of arenaceous deposits in many of the localities it may be concluded that the rate of transgression was comparatively rapid — presumably too rapid too permit of significant marine planation.

That the rate of depression was probably too rapid for significant marine planation isalso suggested by the fact that everywhere beneath the surface of the sediments the Archæan rocks are found in a perfectly fresh and undecayed condition.

Thus although the area must have been exposed to marine planation at the time of Ordovician submergence there is reason to believe that the conditions of submergence were such that the pre-existing surface which must have been of subaërial origin can have been but little modified. The distribution of overlying areas of Paleozoic sediments suggests that the relatively rapid depression which continued through Ordovician time continued until near the close of the Silurian, and it is probable that the middle part of the plain was completely submerged. The eastern and western parts of the plain were still above water-level. If the middle portion was completely submerged at this time, it must have been re-elevated and the sedimentary cover in part removed, for Devonian corals have been found in the Hudson Bay basin with their bases attached to bosses of Archæan rocks. The Devonian sandstones flanking the peneplain on either side also suggest that the middle portions of the plain were subject to subaërial degradation during at least a portion of Devonian time. Of the history of the greater portion of the region from the close of the Devonian to the beginning of the Pleistocene there is no sedimentary record closely associated with the peneplain.

The late Mesozoic has been shown to have been a period of extensive peneplanation throughout most of North America. In New York and Pennsylvania to the south, in Wisconsin and Michigan to the southwest, the remnants of the planation surface have been recognized. In the far northwest strata classed as Cretaceous are found resting apparently upon the peneplain surface. The relations of Cretaceous sediments to a surface apparently coincident with the plain cut upon the Archæan rocks of Wisconsin also suggests that this plain is Cretaceous. It thus seems not improbable that the planation processes of the same period, working northward and eastward from these areas and southward from the Arctic regions, may have in part produced the younger of the two (or more) plains upon the Archæan areas in Canada.

The southern margin of the plain south of Methy portage and around nearly to the city of Montreal is probably of Paleozoic (and pre-Paleozoic) age, since there is little doubt but that it was once covered with Paleozoic sediments. Whether this is true of all that section which lies between the outliers before noted as occurring in the basins of a number of lakes near the central divide seems doubtful. The more detailed study of these basins may show that the Paleozoic sediments which they contain, and which are in every case, except that of Lake Nipigon, significantly below the level of the peneplain, are preserved because thrown into their present protected positions by the downthrow of graben blocks. If so, the probability of this plain being of Cretaceous age will be strengthened. What seems to be a comparable case is known in Scandinavia. The earlier sedimentary rocks were dislocated by a series of faults; later planation left only a few small patches at base-level upon the downthrown parts of the tilted blocks. Subsequent elevation of the whole area, and erosion of these softer remnants, produced a series of depressions in some of which are still found isolated patches of the soft rocks. The lower portions of these depressions frequently form lake basins, the most important of which are Boren, Roxen, Glau, and Braviken.[1]

So far as the geological record is known, it appears that the Labrador portion of the peneplain has never been submerged since Paleozoic time. To this long exposure to subaërial erosion may be attributed the extremely low average gradients of approximately one foot per mile, the lowest found anywhere upon the plain.

3. *The origin of the basins, valleys and gorges.*—The minor basins upon the upland surface, now forming the basins of small lakes, undoubtedly owe their origin to processes of differential disintegration and subsequent erosion and denudation by some agency. The last denuding agent in operation was, of course, the Pleistocene ice-sheets. There is some question, however, as to whether the denudation of the surface is due to these ice-sheets, or to some earlier ice-sheet, or to some other cause. Reference will be made to this in discussing the fourth problem.

The origin of the valleys and gorges incised beneath the plain to a significant degree presents some features of particular interest. Those in which the Cambrian sediments lie may be older than the sediments which they contain, and in that case would be of much earlier date than the main peneplain surface.

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[1] See also Eighteenth Annual Report State Geologist of New York. Part V, pp. 143 ff.

The gorge-like valleys, free from Paleozoic sediments, and the canyons, one would be inclined to think, date their origin from a time subsequent to the planation period. Their immature form, as compared with the broader pre-Cambrian valleys (so called), and the absence of any Paleozoic sediments between their walls suggest this. Most of them are pre-glacial, but some few are post-glacial.

The processes by which they were excavated no doubt were various. Mention has already been made of the opinions of Agassiz and Bell that some of them owe their origin to the erosion of soft disintegrated dike rocks. This may be true in a few isolated cases. In the great majority of cases, however, particularly of the larger of these gorges, other and more general processes must have been in operation.

Given time enough, there can be no question but that the normal processes of river erosion could produce these deep canyons or steep-sided valleys. So far as we know at present, this seems to have been the process by which most of the deep gorges and canyons cut below the level of the Labrador peneplain were excavated. Low notes with respect to the canyon of the Hamilton, just below the Grand Falls, that the river in its erosion of this gorge has been guided by two series of joint fractures, so that the canyon has a somewhat zigzag course. Mr. Low has also drawn the writer's attention to the fact that there are several instance where an old valley has been blocked by glacial débris, and the streams flowing in the upper portions of the valleys are turned aside, and have already cut well-defined canyons, in some cases of considerable length, in the crystalline rocks. It is to be noted that the canyon of the Hamilton River enters the older valley, to which reference has already been made, from the north side. The old valley continues inland for a considerable distance beyond the junction of the present Hamilton River, *via* the canyon, with the lower part of the stream in the older valley. Mr. Low regards this canyon as of post-glacial origin and due to erosion by the large stream which now rushes through it.

The problem of the origin of the deep canyons across the

Laurentian swell by which the drainage from the main divide in the interior of Labrador reaches the St. Lawrence River is much more complex. One would expect the drainage of such a region to find its way outward toward the southwest, somewhere along the line of the present St. Maurice River. At the present time almost all the streams flow nearly at right angles to this apparently normal direction and cross the St. Lawrence swell in very straight courses by deep, steep-sided gorges or canyons.

The transverse drainage has been explained by assuming that the gorges through which the streams flow were produced by some cataclysm, either by the production of gigantic gaping fractures or by the down faulting of narrow graben blocks. The only evidence upon which this theory is based seems to be the existence of the gorges themselves, and the apparent difficulty of otherwise accounting for the courses of the incisions in a direction which is almost at right angles to what would be considered the normal one. There are, however, at least two other well-known processes by which features such as these could be normally developed.

In the first place, the swell may not have been in existence at the time when the streams were first beginning to flow and the gorges were not cut. The edge of the plateau may have been arched up slowly by the same forces which produced the Appalachian folds of the New Foundland and Acadian areas,[1] or by more recent dynamic processes. Provided this gentle arching proceeded slowly enough, the streams might have persisted in their original direction, apparently a consequent one (as suggested below) sawing their way into the ridge as rapidly as it rose. In brief, the streams may be *antecedent* rivers. While this process was going on in the southeast, the rivers on the other side of the main divide would, provided they had an equal capacity for work — a function of their volume and grade — have been competent either to have cut out longer and deeper gorges or to have widened their valleys. The information at present available is not sufficient to decide the question. Mr. Low has drawn the writer's attention to the fact that the bottoms of the channels of the westerly and northwesterly flowing streams are almost graded, although, on account of the steepness and shortness of the descent from the plateau to the coastal plain, they are an almost continuous series of impassable rapids. On the other hand, in the case of the channels of many of the streams flowing to the St. Lawrence we find a series of step-falls or rapids with quiet reaches above and with steep canyon walls beside the falls, so that these latter, though they have cut out deep valleys, are yet in a less mature stage than those on the other side of the divide.

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[1] Daly has recently shown that the post-Pleistocene beaches on the northeast coast of Labrador have undergone differential elevation since they were formed (9).

It should also be noted that the general direction along which the streams would develop by normal erosive processes would be determined, as in the case of the gorge of the Hamilton River, by lines of structural weakness in the rocks, not necessarily by lines of open fracture.

A second theory would regard the majority of these valleys as the incisions of *superposed streams*. The Paleozoic sediments in the basin of Lake St. John are usually supposed to indicate a transgression of the Paleozoic sea into this locality, and at least suggest that at one time the whole adjacent region was buried beneath the Paleozoic sediments. The small remnant of an ancient belted coastal plain found between Montreal and Quebec, and farther east in Anticosti and the Mingan Islands, show that there, where the Paleozoic sediments were undisturbed by the orogenic movements of late Paleozoic time, normal processes of erosion produced normal topographic forms. It seems not unnatural to suppose that consequent streams developed on the coastal plain would, when they reached the hard rock beneath, have still persisted in their initial consequent direction. In this connection attention may be drawn to a gorge on the Betsiamites River. Low writes:

> Next turning to the northeast, the river, for a distance of eight miles, breaks in a straight line through the Labradorite hills, which form almost vertical walls on either side, rising from two hundred to four hundred feet above the water (20, p. 7).

The description of the river course and the country on either side, below and above this gorge, would suggest that the Labradorite hills here referred to rise as a monadnock above the level of the plain, and that the stream to cut through them must have been superposed upon them.

Whether these gorges were developed by catastrophic processes, or owe their origin to antecedent or superposed streams, or to some other cause, a few of them have probably been modified by subsequent ice-action. In all cases they lie in a position transverse to the direction of ice-motion. In many cases, particularly toward the northeast, the probability is that the ice, retarded in its progress from central Labrador by the ascent of the main divide, had little effect. Toward the center and western part of this division of the plain, in the vicinity of Lake St. John and elsewhere, the effect of the glacial ice in modifying these valleys is more apparent. Writing of his ascent of the Betsiamites River, Low mentions incidentally a tributary of this river which "descends into the valley by a beautiful falls, over one hundred feet high" (20, p. 6). The main valley varies in width from a quarter of a mile to over a mile, and is more or less filled with glacial débris. The relation of this tributary lateral valley to the main valley certainly suggests that the main valley has been significantly widened and deepened by a glacial distributary from the interior. The best-known of the gorges is that of the Saguenay. It is a typical fiord valley with ice-scoured sides. Its relation to the St. John basin suggests that it owes its present form to the scouring by an ice-stream which made its way outward from the basin. The Labrador ice, although retarded in its flow by the ascent of the main divide, would attain a considerable thickness in this basin after it had passed the divide. Although it probably, at one time, passed over the St. Lawrence swell, the main ice-stream, after leaving the St. John basin, moved toward the southwest. If, however, there existed a deep river canyon leading outward from the basin, similar to the many found farther northeast, the depth of ice in the basin and the tendency for the pressure to force the ice outward in every direction along the lines of least resistance would cause an ice-stream to pass out in this direction toward the St.

Lawrence, even at a time when no significant amount was passing over the subdivide between the basin and the river. This ice-stream, moving in a well-defined channel, would deepen and widen the pre-existing river gorge. It thus seems probable that the Saguenay gorge may be regarded as the channel of a glacial distributary from the St. John basin, and that it was in existence prior to the advent of the ice, as a stream channel similar in form to those which exist farther northeast and show no significant modification of form due to ice-action.

With reference to the older valleys, north of the main divide in Labrador, containing pre-Cambrian sediments, the descriptions available are inadequate to enable one to determine whether they have been significantly widened and deepened by ice-erosion. In the case of the old valley of the Hamilton River lateral tributaries plunge or cascade over the margin into the main valley. This may be true of other similar valleys. It has already been intimated that the lack of adjustment between the tributary and the main valley may be due to relatively recent downfaulting of graben blocks.

Reference has already been made to the possible origin of the submerged gorge of Lake Temiscaming and the Ottawa River valley above Mattawa.

There are also a number of minor gorges, such as those mentioned by Barlow as occurring on the peneplain west of Lake Temiscaming, whose courses are in some cases transverse to hard and soft strata alike; or others, such as the gorge on the Upper Abitibi mentioned by Parks, which may be the channels of superposed streams, may have been eroded along the line of weak dike-rocks, or may be due to some other cause.

4. *The origin of the smooth fresh surface of the Archæan rocks.*—As has been intimated in the previous description of the peneplain, the old soil cover of subaërial origin has everywhere been removed. For this has been substituted a covering of material, much of which undoubtedly was derived from the Archæan terranes, but almost all of which has been brought to its present resting-place by the aid, direct or indirect, of the Pleistocene ice-sheets. Uncovered Archæan bosses often project above this

secondary cover. Everywhere that the bed-rock surface is known, whether covered or not, it presents a smooth, hard surface, free from the products of decay *in situ*. But not only is this true of the portion of the plain remote from the bordering Paleozoic sediments, but the work of Laflamme, Adams, Lawson, and others has shown that it is true of the localities adjacent to and *under* the Paleozoic cover.[1] Around the southern border of the peneplain, in the Lake St. John region, in the Moose River basin, and in a few other localities, the *actual contacts* between the Paleozoic sediments and the pre-sedimentary peneplain surface are known. In these cases it will be recalled that the peneplain facet upon which the sediments rest is probably that of an earlier cycle than the main Canadian peneplain. Now, in every case where these contacts have been met with and examined it is found:

1. That the crystalline rock surface under the sediments *in situ* is as little altered as in the ice-scoured surface perhaps twenty feet away.

2. In some few localities the pre-sedimentary crystalline surface retains some traces of decay, such as pits and pockets, now filled with small outliers of sediments, isolated more or less from the larger masses. Such pitted surfaces occur near Kingston. The best known case is that described by Bell as occurring on Benjamin Island, Lake Huron.

3. In only one locality south of the main divide has an actual arkose, which is presumably derived from the decay of near-by granitic rocks, been reported *in situ*. This forms the lowest member of the Ordovician series of the locality, and rests upon the fresh surface of a gneiss. The basal members of the pre-Cambrian rocks in northern Labrador are arkoses whose materials probably have not been transported very far.

As regards the apparently significant absence of arkose deposits (which might be regarded as old soils *in situ*) from beneath the Paleozoic sediments, it is to be noted that in almost all cases where the *actual* contacts between the sediments and the crystallines are known they occur at the summits or on the flanks of the crystalline ridges or domes. So far as the author is aware, no case has been reported in which the *actual* contact between the two was located in or near the bottom of one of the characteristic pre-sedimentary basins. In fact, it unfortunately happens that most of these contacts must be below the present local water level. Hence at present we are only justified in stating that the summits and sides of the crystalline ridges beneath the sediments are as bare and as little decayed as are the similar ridges away from the sediments.

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[1] For references and details see 41, pp. 146–53.

The condition of the surface beneath the sediments shows that processes which could produce a denuded fresh rock surface were in operation long before the Pleistocene. As to what these processes may have been there is considerable room for divided opinion.

Glacial erosion would seem to be competent to remove soft material from localities where disintegration had penetrated deeper than elsewhere. In the process it would scour the less disintegrated residuals and would thus produce the characteristic topography of the upland everywhere. The depth to which it would scour the bed rock itself is, of course, at present indeterminate away from the regions underlain by sediments, but it has produced no noticeable discordance between the parts of the buried crystalline ridges protected by the sediments and *closely* adjacent parts not thus protected. Again, if the bare, fresh surface has been produced by glacial scouring, it would seem that we must infer a pre-Paleozoic glacial period during which the sub-Paleozoic peneplain was scoured off. Of such a period, beyond the existence of the scoured plain itself, there is, in the regions under discussion, no known recorded evidence.

In this connection it may be well to recall that Dr. Geikie has described a somewhat similar surface occurring over a small area of Laurentian gneiss in northwest Scotland (Ross and Sutherland counties). He drew attention to the fact that this mammillated surface passed beneath the younger sediments, and notes that it is strongly suggestive of presedimentary glacial erosion.

The deep soils of the earlier peneplain might have been removed from the ridges, leaving them comparatively fresh, by some such process of erosion as McGee describes under the title of "Sheet flood erosion" (28). He describes the surface of a portion of the subarid Sonora district in southern California as being a plain cut on crystalline rocks, with little soil cover *in situ.* In some features this plain resembles that of the Canadian peneplain, but it has relatively a very limited area. On the Canadian peneplain, however, the basins as well as the ridges are free from rock débris *in situ.*

The normal processes of subaërial erosion or of marine erosion do not seem competent to remove the material from the basins as well as from the ridges; and, in addition, they do not produce residual land forms with surfaces so little decomposed as are the crystalline surfaces everywhere.

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